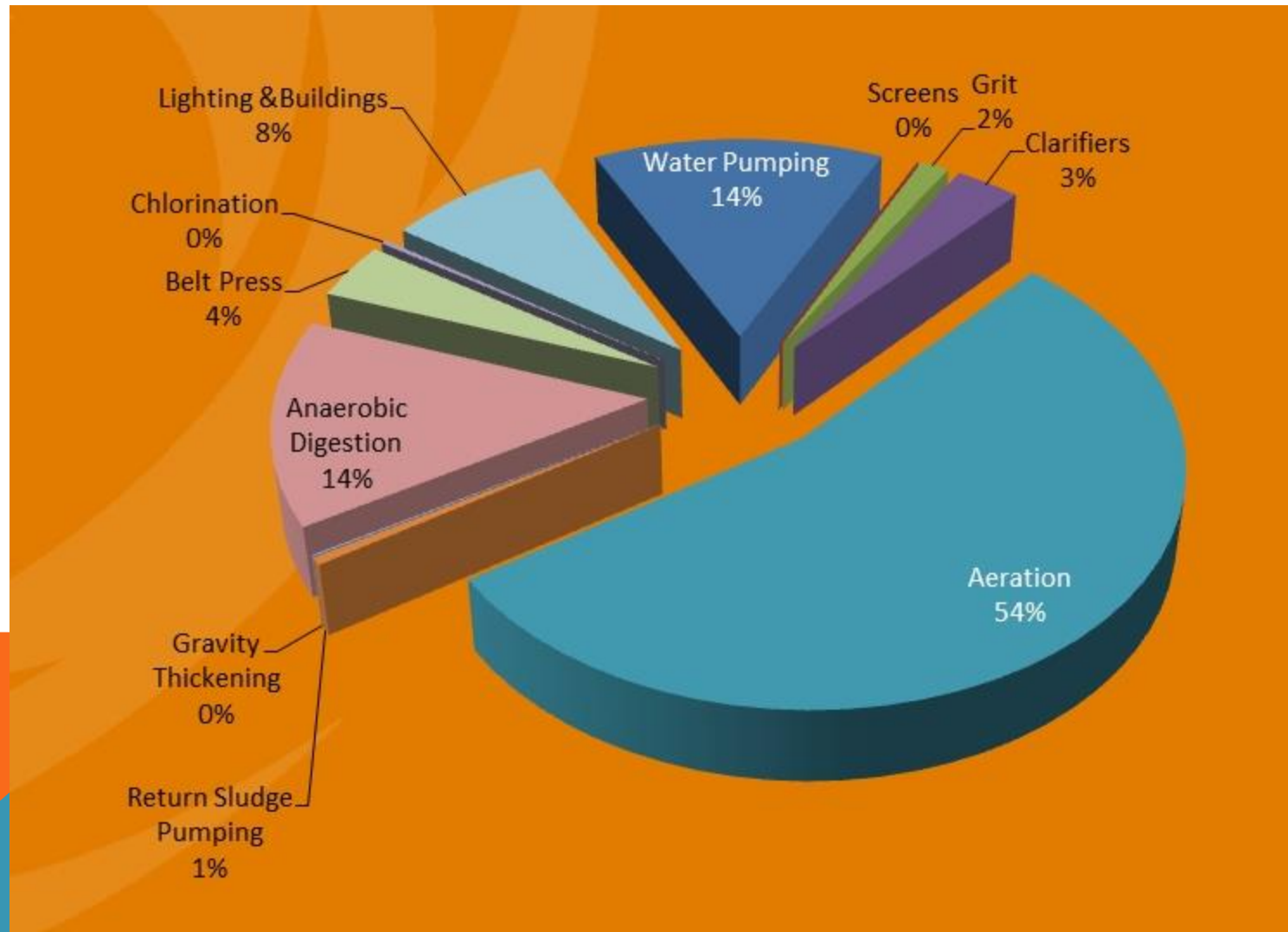


ENERGY EFFICIENCY - WASTEWATER TREATMENT PLANTS


GLENN T. CUNNINGHAM, P.E., PHD

AREAS OF ENERGY USE FOR WASTEWATER PLANTS

- Typical Energy Consumers in a WWTP



AREAS OF SIGNIFICANT ENERGY USE

- **Aeration**
 - Blowers
 - Air compressors
 - Mechanical mixers
 - **Pumps**
 - Inefficient flow control methods: throttling
 - Pumping at higher flow rates than are necessary
 - **UV disinfection**
 - Running more lamps than are needed – plant is not operating at its rated capacity
 - Changing lamps out too soon – Plant may change UV lamps every year when they have an expected life of 18 months
- 

AREAS OF SIGNIFICANT ENERGY USE

- **HVAC**
 - Set-back thermostats
 - Avoid electric resistance heat
 - Perform proper maintenance
 - Replace units when their useful life is over
- **Lighting**
 - Turn off when not needed
 - Consider occupancy sensors to shut off lights when no one is around
 - Convert to more efficient fixtures
 - LEDs are becoming much cheaper and dependable
- **Combined Heat and Power**
 - Use biogas to generate electricity and recover heat for digestion and space heat

FANS/BLOWERS



FANS/BLOWERS


- **Plants often operate at less than design loads**
 - Determine actual BOD and operate only as much aeration equipment as is needed
 - Turn off unneeded blowers
 - If VFDs are installed reduce blower capacity to supply only the required air
 - Example: Newnan Utilities installed one VFD on one of three 125 HP blowers serving the WWTP and saved a reported \$24,000/year in electrical cost

NEWNAN UTILITIES WWTP




Blower efficiency enhanced
with variable frequency drives


PROJECT SUMMARY

- **First they upgraded the 20+ year old blowers**
 - Replace worn parts
 - Clean internal parts
 - Upgrade from 100 HP to 125 HP motors
 - Added instrumentation to measure vibration, inlet air temperature and bearing temperature
 - Added surge protection
 - **Installed 1-VFD on one of the three blowers serving a common header**
 - **Upgraded the control system**
- 

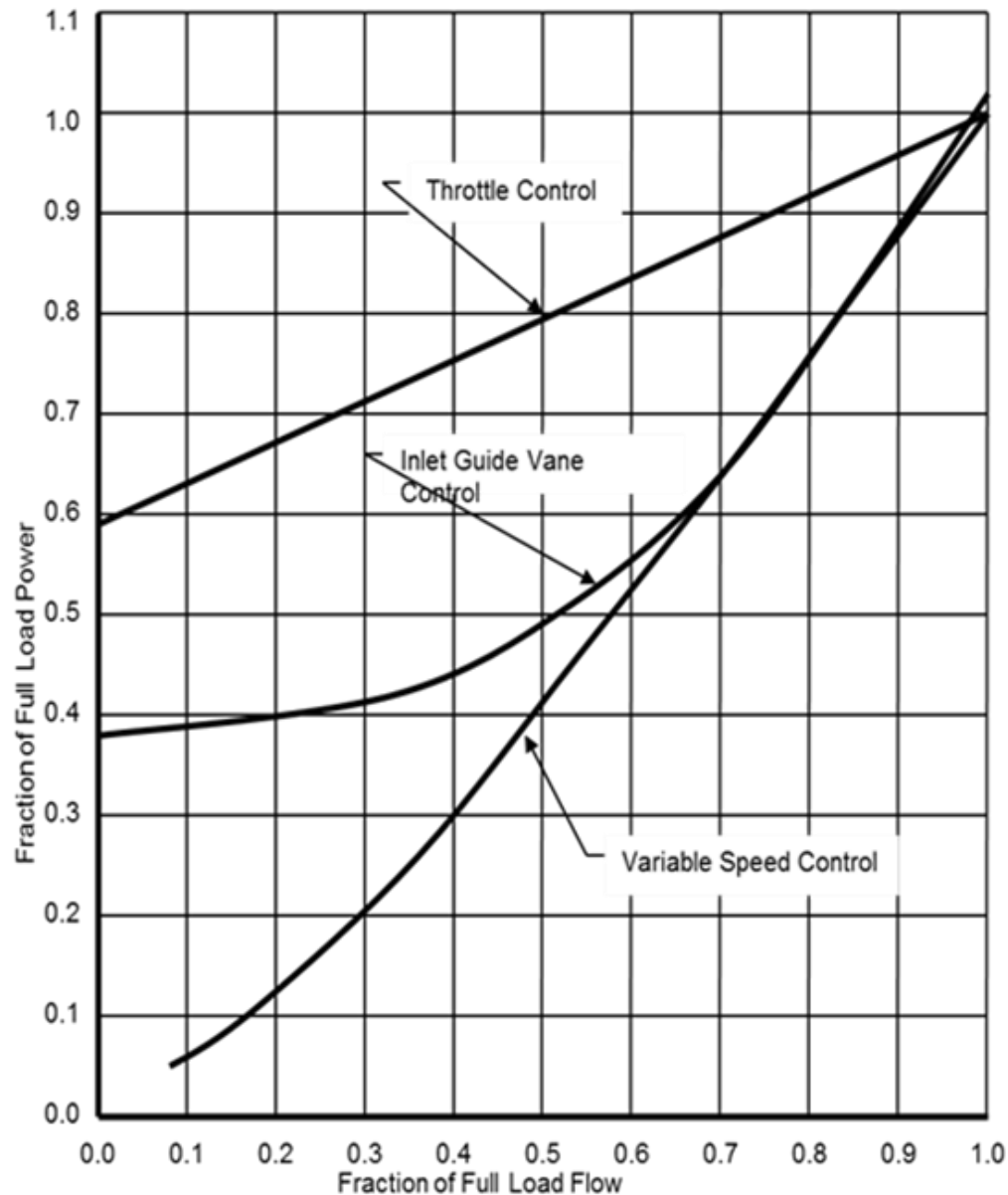
SYSTEM OPERATION

- Biological processing consists of three basins connected in series
 - Utility uses a handheld probe to determine basin dissolved oxygen content
 - Personnel manually adjust blower kW set point on operator interface terminal
 - PLC automatically adjusts blower speed to maintain kW set point
 - Automatic adjustment accounts for changes in ambient air temperature that change inlet air density
 - Hotter air – higher RPM; colder air – lower RPM
- 

SYSTEM OPERATION

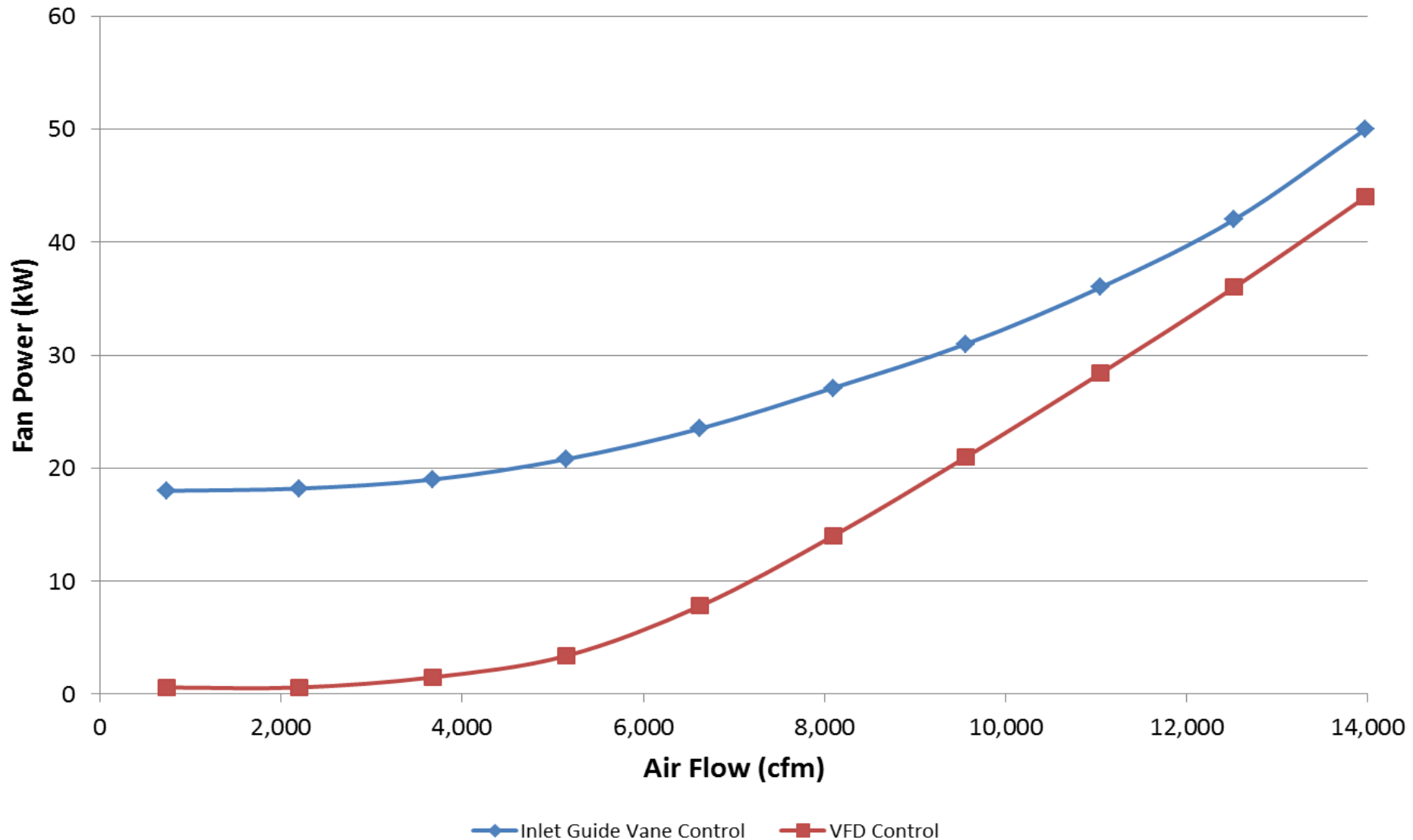
- If required air flow exceeds single blower capacity a second blower can be started and the VFD blower's speed ramped back
 - However, these two blowers operating together represent a large jump in air flow and power compared to one blower working alone at full speed
 - The VFD can “over-speed” the single motor to remain in operation with one blower until air demand exceeds the blower and motor capacity of the VFD blower
 - This strategy saves additional operating cost
 - Savings are quoted at \$24,000/year
- 

FAN/BLOWER CAPACITY MODULATION METHODS



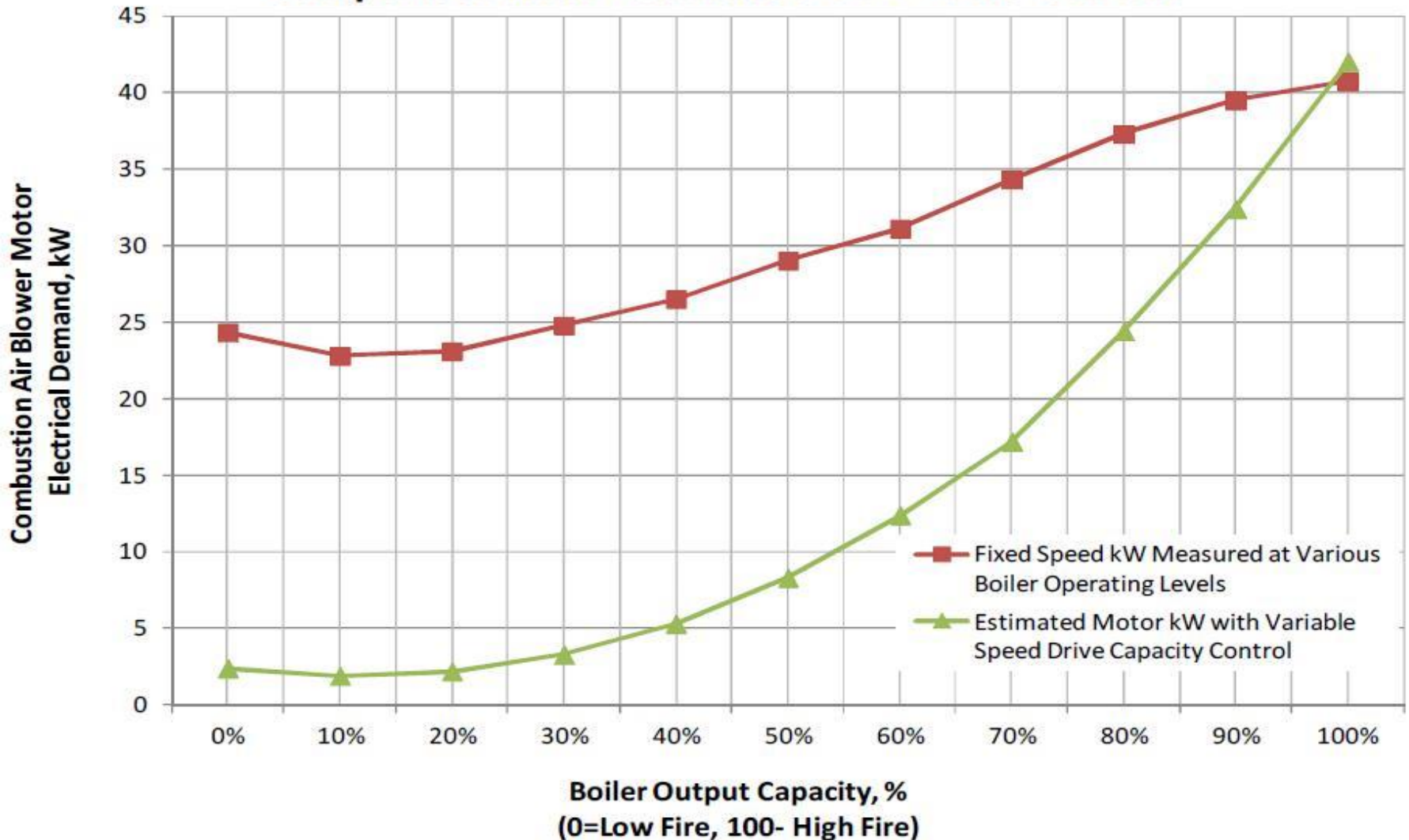
FAN/BLOWER – VFD CONTROL

VFD vs Inlet Guide Vane Fan Control

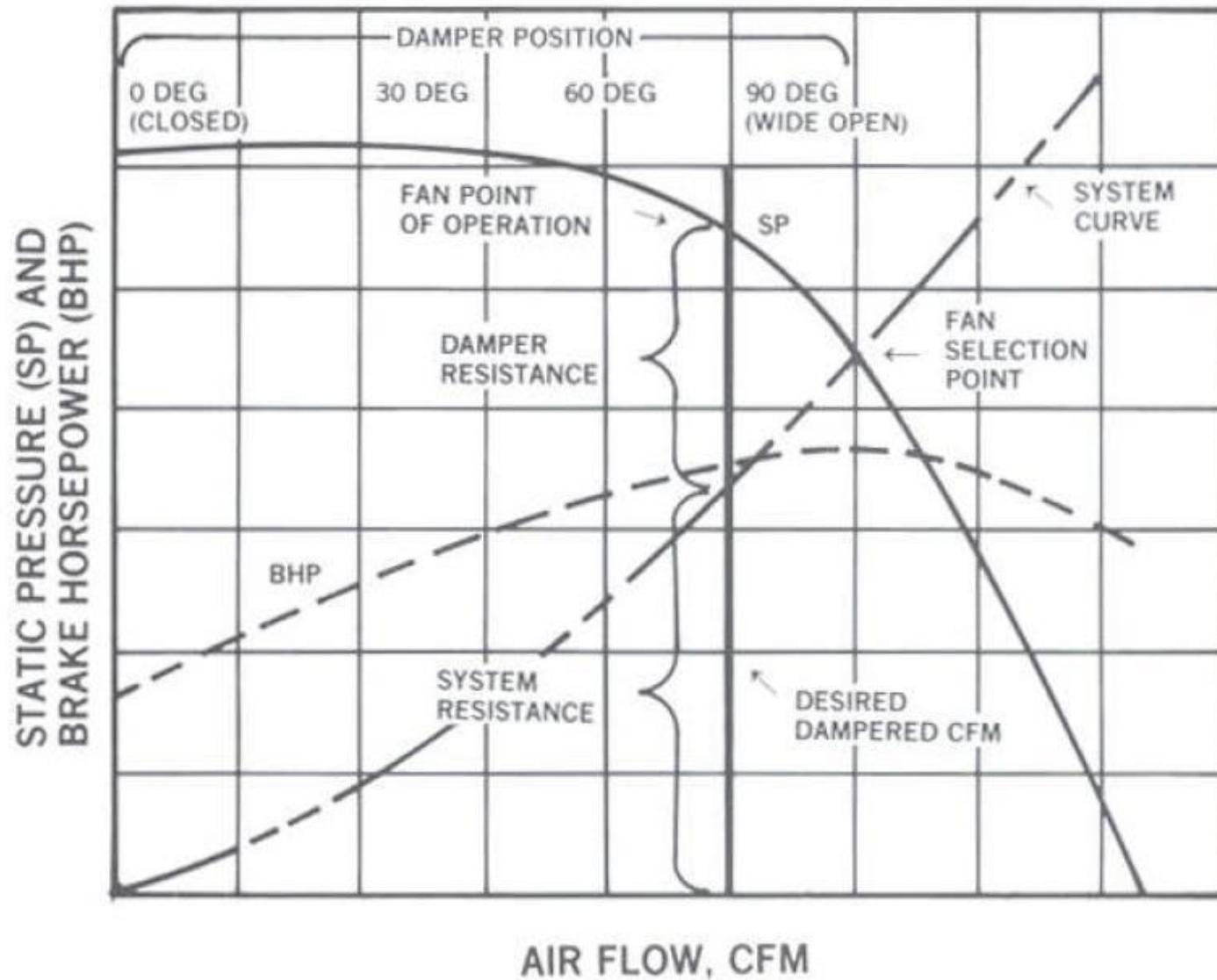


BOILER COMBUSTION AIR FAN

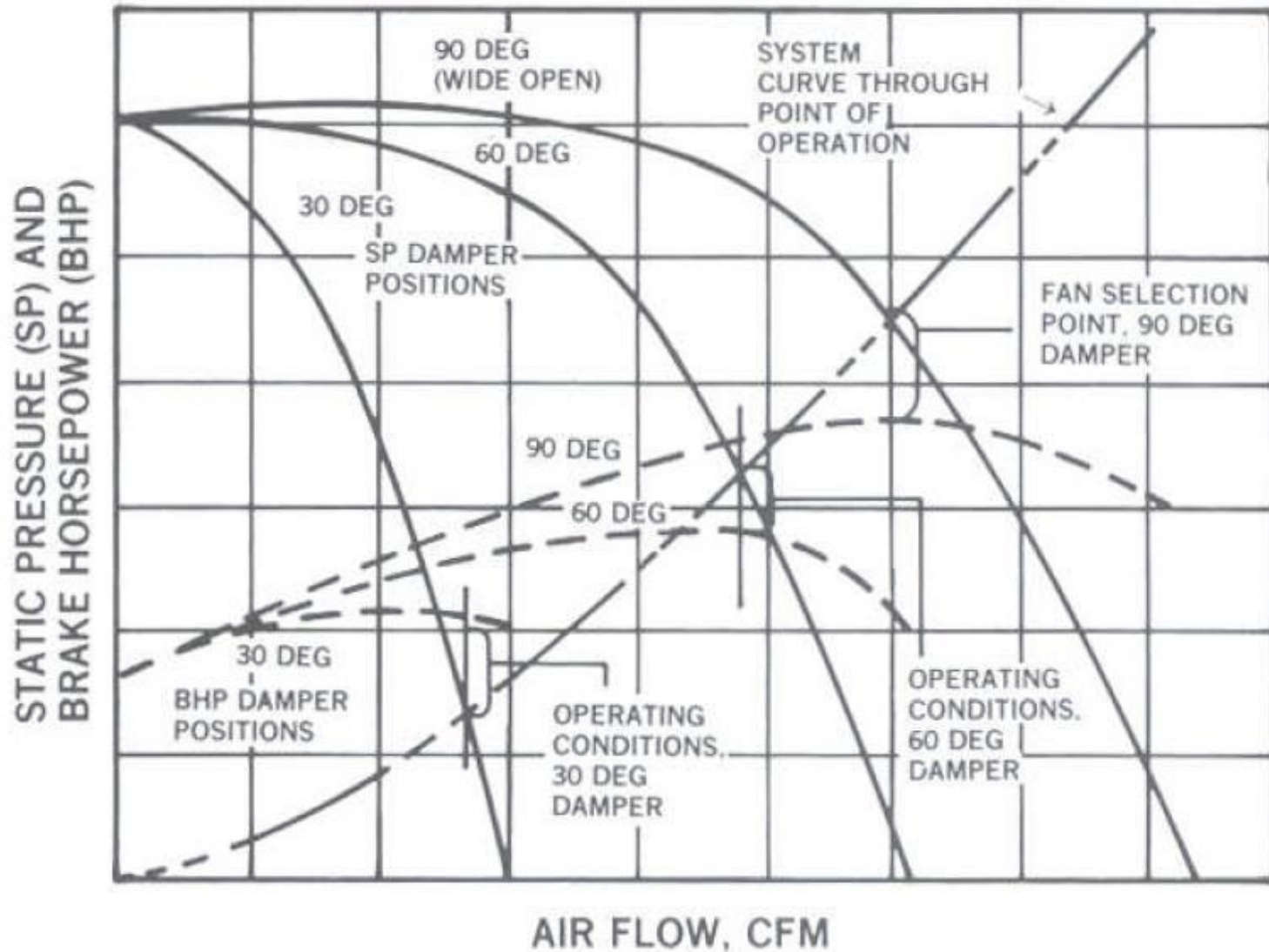
#2 Boiler 50 hp Fixed Speed Combustion Air Blower with Outlet Damper Control - Measured Electrical Demand Comparison with Estimated VFD Drive Control



FAN OUTLET DAMPERS (VANES)



FAN INLET GUIDE VANES



FAN LAWS

VOLUME

$$CFM_2 = CFM_1 \left(\frac{RPM_2}{RPM_1} \right)$$

VARIES DIRECT WITH SPEED RATIO

PRESSURE

$$P_2 = P_1 \left(\frac{RPM_2}{RPM_1} \right)^2$$

VARIES WITH SQUARE OF SPEED RATIO

HORSEPOWER

$$HP_2 = HP_1 \left(\frac{RPM_2}{RPM_1} \right)^3$$

VARIES WITH CUBE OF SPEED RATIO

FAN LAWS

A **10%** reduction in speed (rpm) will result in a **27%** reduction in power

$$\begin{aligned}\text{Change in kW} &= [\text{rpm}_2/\text{rpm}_1]^3 \\ &= [\text{cfm}_2/\text{cfm}_1]^3\end{aligned}$$

If $\text{rpm}_1 = 100$ and $\text{rpm}_2 = 90$

$$\text{kW}_2 = [90/100]^3 = 0.73 \text{ or a } \underline{\underline{\mathbf{27\%}}}$$

Reduction

PUMPING

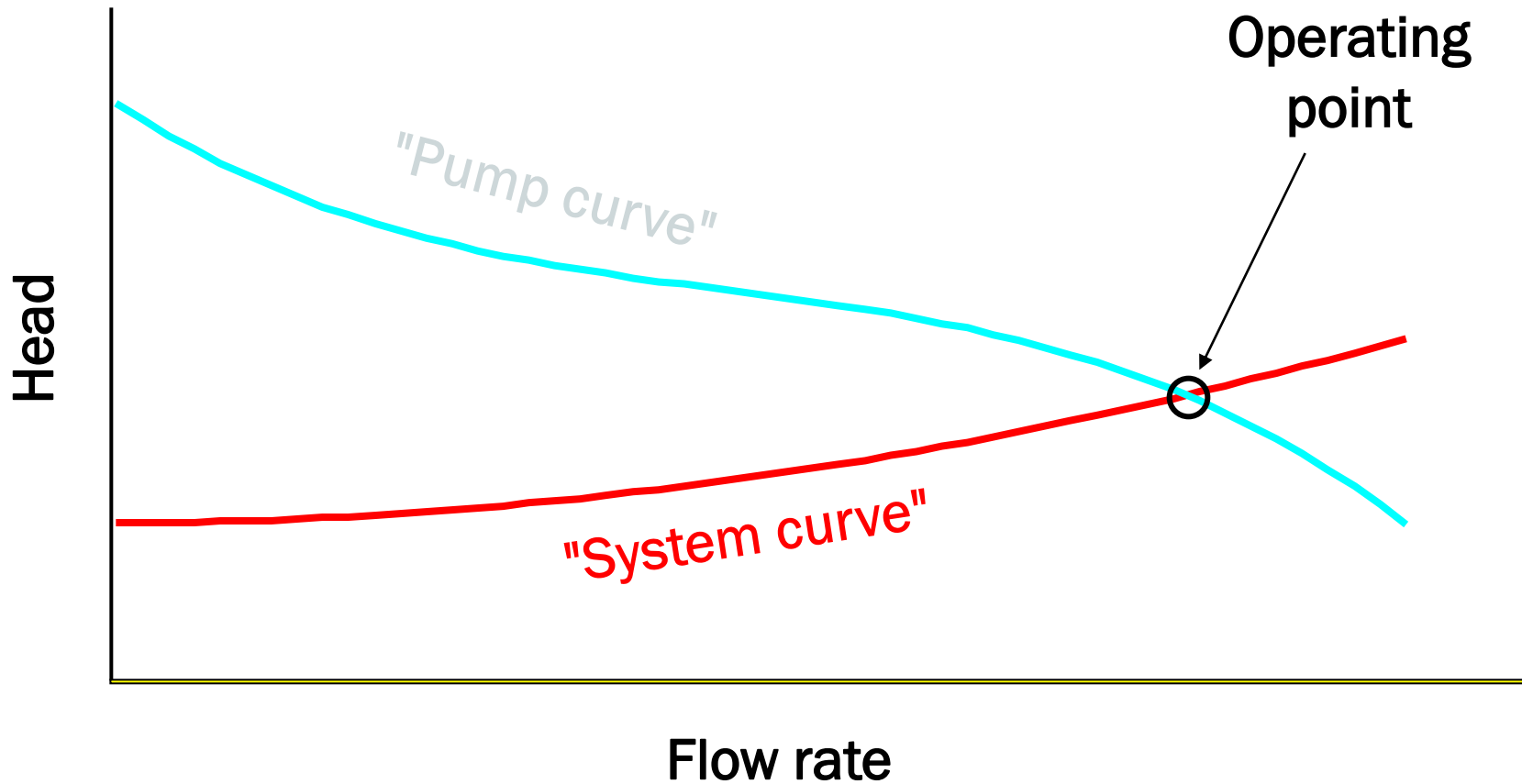


Pump energy basics are fundamental to secondary prescreening

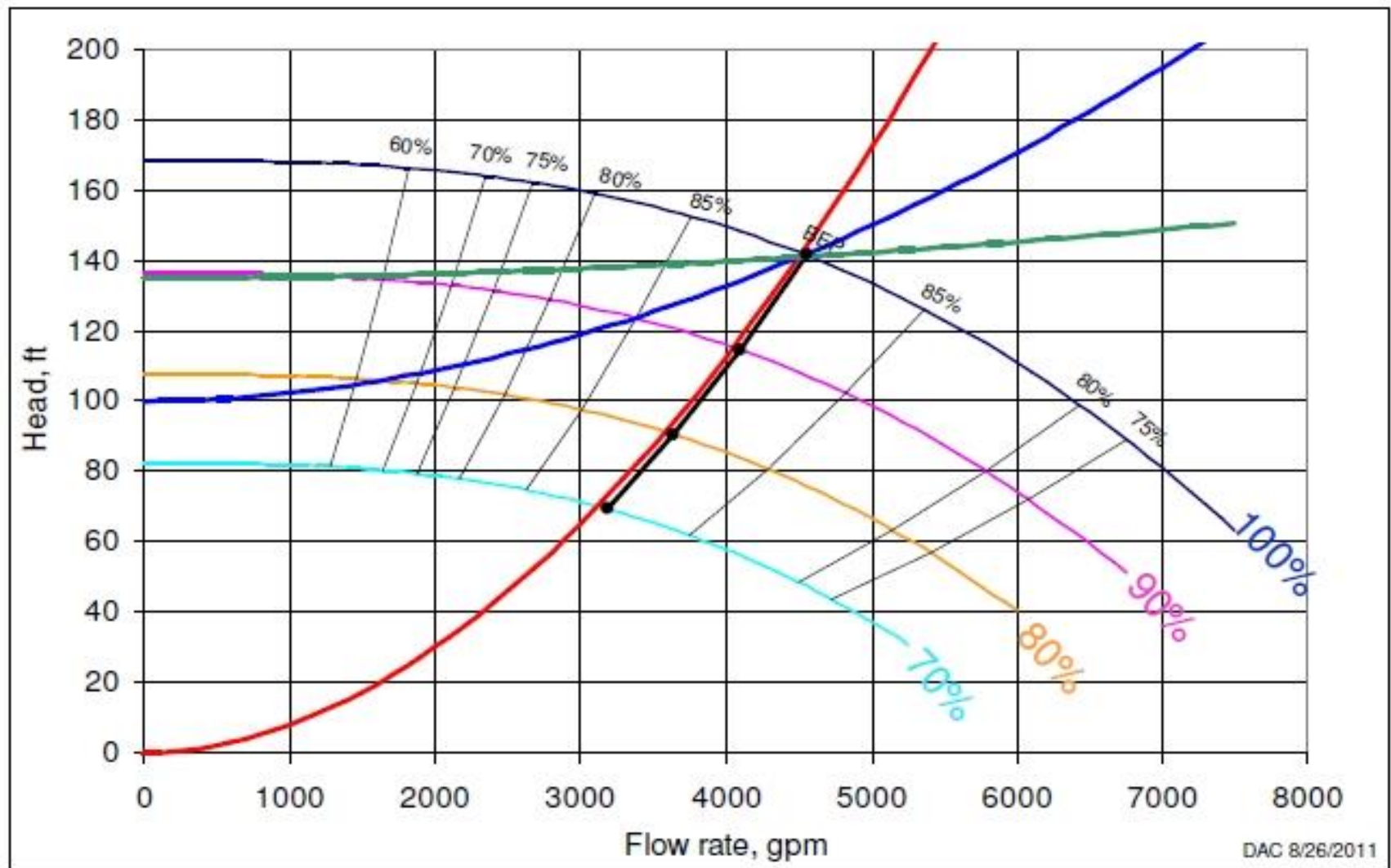
$$E = \frac{Q \cdot H \cdot T \cdot sg}{5308 \cdot \eta_{\text{pump}} \cdot \eta_{\text{motor}} \cdot \eta_{\text{drive}}}$$

E	energy, kilowatt-hours
Q	flow rate, gpm
H	head, ft
T	time, hours
sg	specific gravity, dimensionless
5308	Units conversion constant
η_{pump}	pump efficiency, fraction
η_{motor}	motor efficiency, fraction
η_{drive}	drive efficiency, fraction

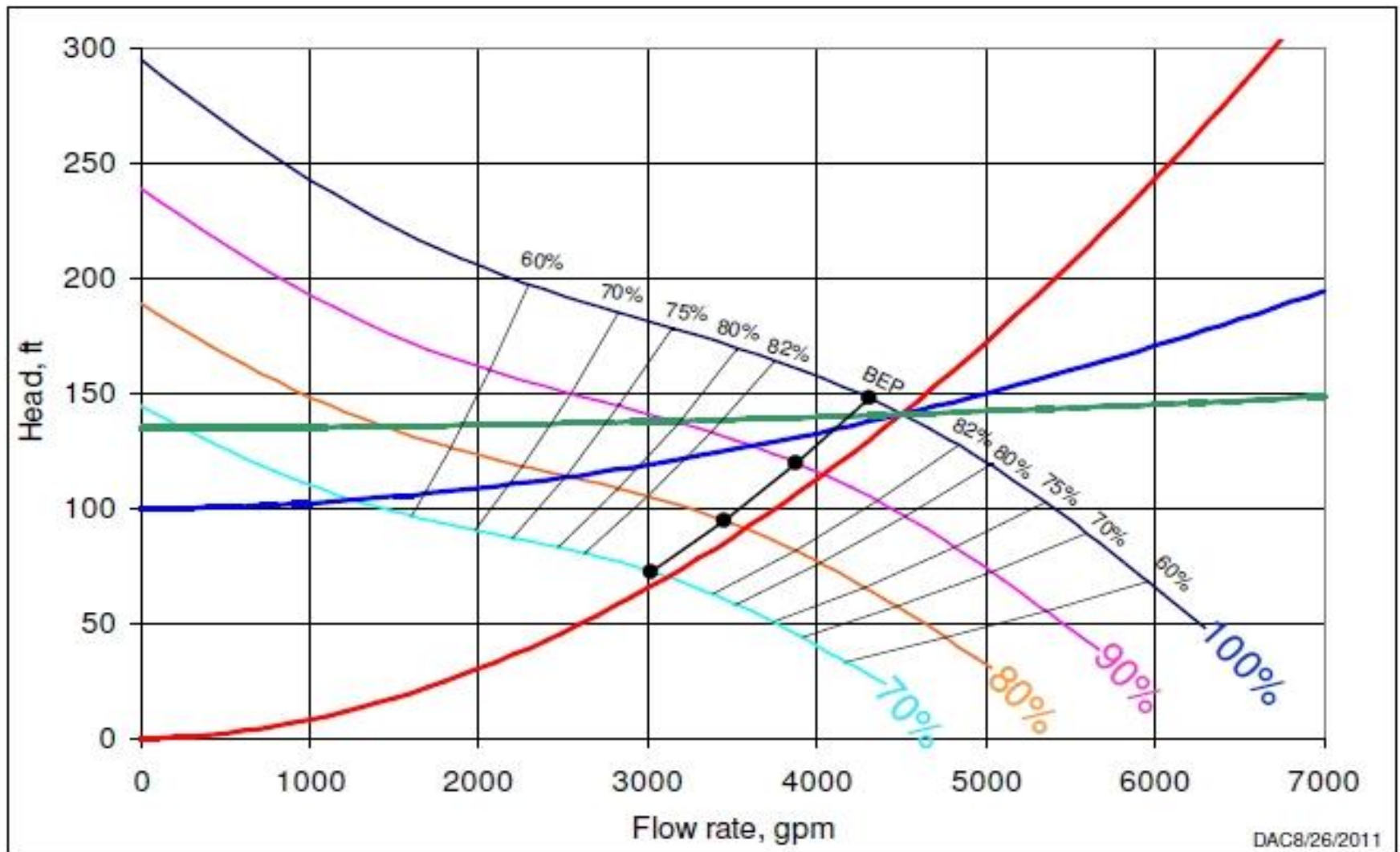
THE SYSTEM OPERATING POINT IS AT THE INTERSECTION OF THE PUMP AND SYSTEM HEAD - CAPACITY CURVES



All three system curves with P2, variable speed

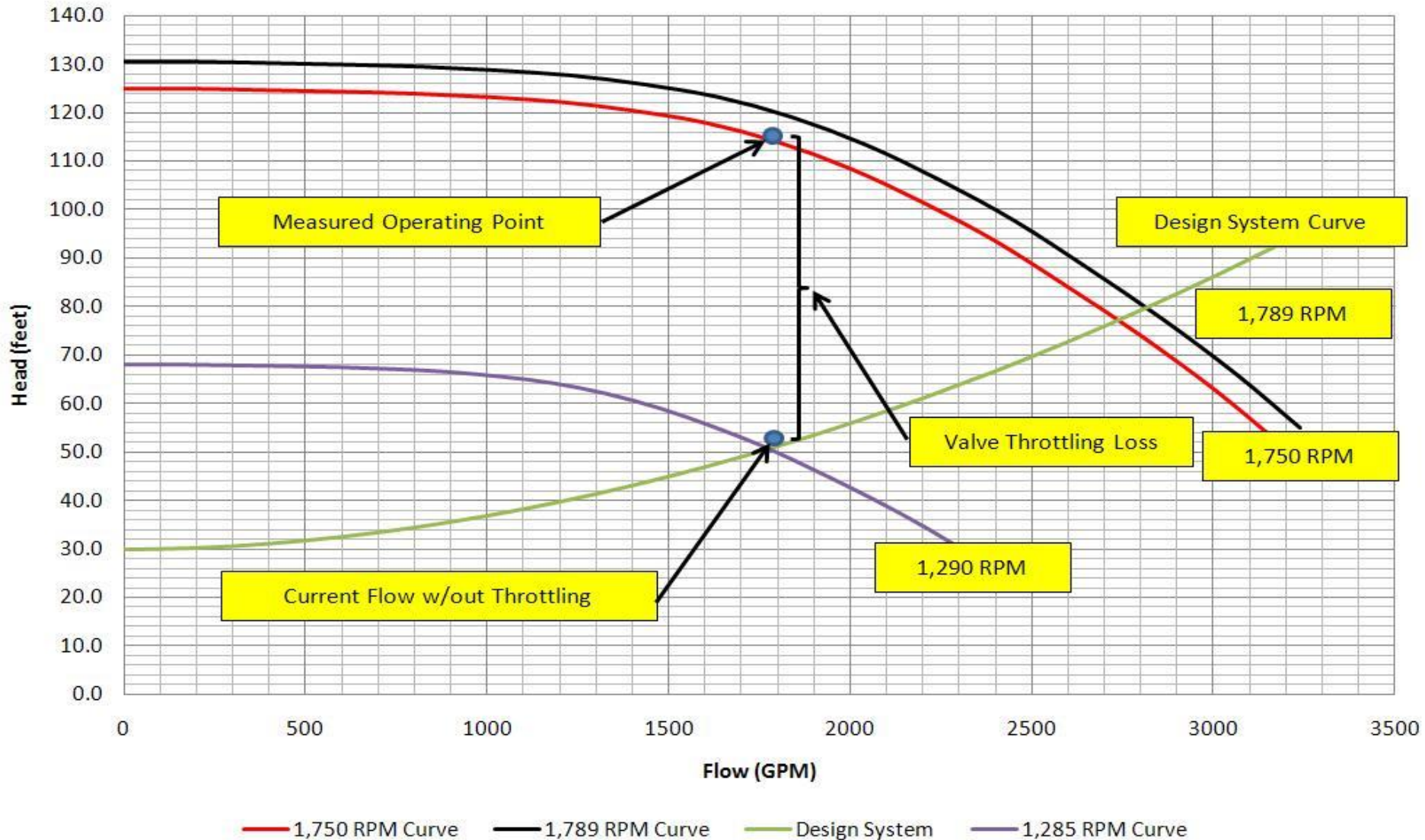


All three system curves with P3, variable speed



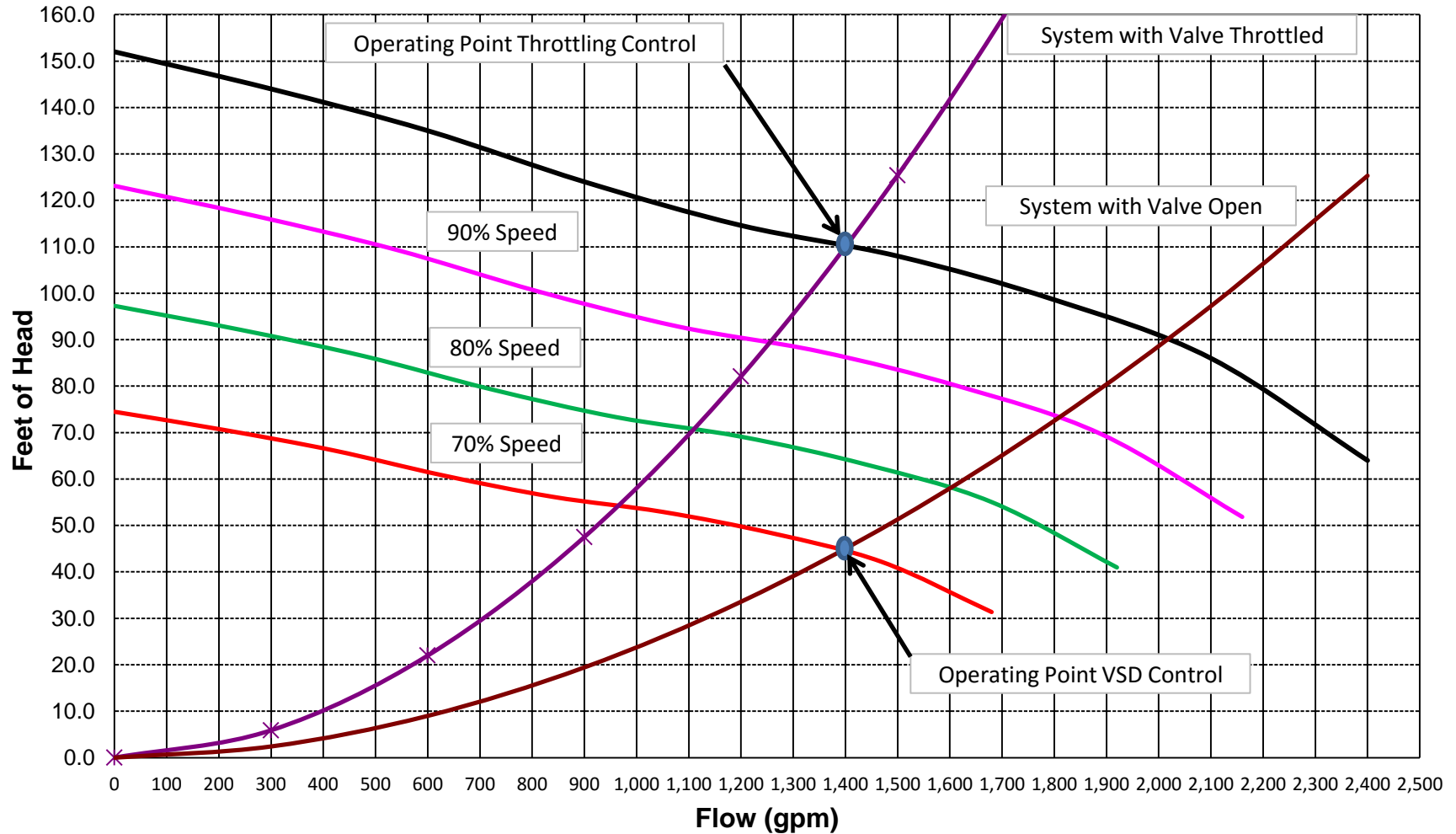
OVERSIZED CONDENSER WATER PUMP

Condenser Tower Pump #2



ACTUAL PUMP DATA FOR VSD OPERATION

Variable Speed Pumping



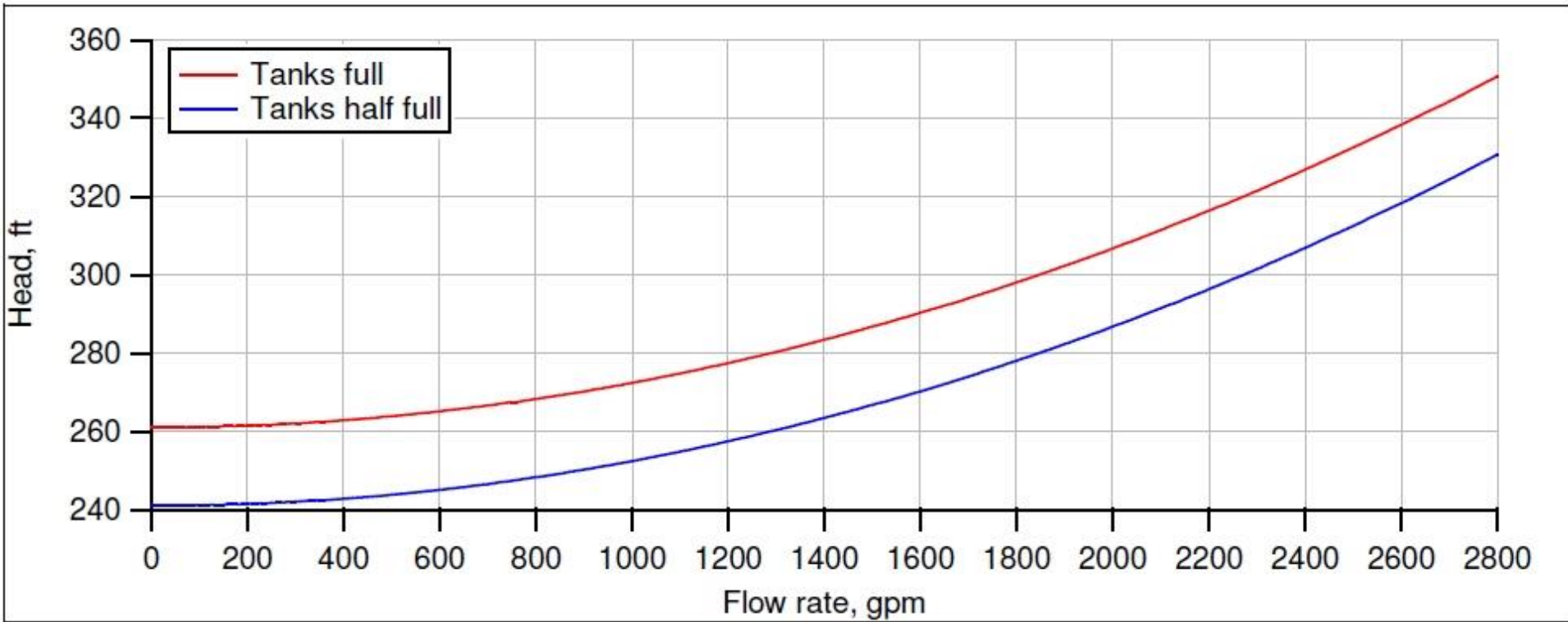
EXAMPLE WATER TREATMENT PLANT

- County water treatment facility
 - 200 HP pump
 - 2 100 HP pumps
 - Typically run the 200 HP and one 100 HP
- Peak demand is just under 1.6 MGD
- Demand is less than 1.5 MGD 99.5% of the time
- Would like to operate the plant 12 hours/day or less
- Electric rate has a significant demand charge



EXAMPLE WATER TREATMENT PLANT

System Curves



CITY WATER SYSTEM

						Monthly unit costs: 1.2 MGD						
Pump gpm	ft	Required MGD	hrs/ day	operating fraction	PSAT kW optimal	kwhr	Demand charge	Energy charge	Service fee	Tax	annual cost	avg. \$/ kWhr
1700	294.1	1.2	11.76	0.490	113.6	40651	\$628	\$1,809	\$9	\$147	\$31,106	0.0638
1800	298.1	1.2	11.11	0.463	121.6	41096	\$707	\$1,823	\$9	\$152	\$32,293	0.0655
1900	302.3	1.2	10.53	0.439	129.8	41559	\$788	\$1,838	\$9	\$158	\$33,512	0.0672
2000	306.8	1.2	10.00	0.417	138.5	42127	\$873	\$1,856	\$9	\$164	\$34,837	0.0689
2100	311.4	1.2	9.52	0.397	147.4	42699	\$961	\$1,875	\$9	\$171	\$36,189	0.0706
2200	316.4	1.2	9.09	0.379	156.4	43247	\$1,050	\$1,892	\$9	\$177	\$37,543	0.0723
2300	321.5	1.2	8.70	0.362	165.9	43879	\$1,144	\$1,913	\$9	\$184	\$38,995	0.0741
2400	326.9	1.2	8.33	0.347	175.8	44560	\$1,242	\$1,935	\$9	\$191	\$40,517	0.0758
2500	332.5	1.2	8.00	0.333	185.8	45211	\$1,340	\$1,956	\$9	\$198	\$42,039	0.0775
						Monthly unit costs: 1.5 MGD						
Pump gpm	ft	Required MGD	hrs/ day	operating fraction	PSAT kW optimal	kwhr	Demand charge	Energy charge	Service fee	Tax	annual cost	avg. \$/ kWhr
1700	294.1	1.5	14.71	0.613	113.6	50814	\$628	\$2,136	\$9	\$166	\$35,270	0.0578
1800	298.1	1.5	13.89	0.579	121.6	51370	\$707	\$2,154	\$9	\$172	\$36,502	0.0592
1900	302.3	1.5	13.16	0.548	129.8	51948	\$788	\$2,173	\$9	\$178	\$37,769	0.0606
2000	306.8	1.5	12.50	0.521	138.5	52659	\$873	\$2,195	\$9	\$185	\$39,152	0.0620
2100	311.4	1.5	11.90	0.496	147.4	53374	\$961	\$2,219	\$9	\$191	\$40,562	0.0633
2200	316.4	1.5	11.36	0.473	156.4	54059	\$1,050	\$2,241	\$9	\$198	\$41,973	0.0647
2300	321.5	1.5	10.87	0.453	165.9	54849	\$1,144	\$2,266	\$9	\$205	\$43,489	0.0661
2400	326.9	1.5	10.42	0.434	175.8	55701	\$1,242	\$2,293	\$9	\$213	\$45,081	0.0674
2500	332.5	1.5	10.00	0.417	185.8	56514	\$1,340	\$2,320	\$9	\$220	\$46,670	0.0688
200-hp motor capable of handling loads through 2200 gpm (in service factor for 2200 gpm)												
250-hp motor required for 2300 gpm and above												

Figure 15. Spreadsheet showing optimal energy cost at various pump flow rates, based on average daily demands of 1.2 and 1.5 million gallons.

Energy charge:	First 15,000 kWhr each month @ 6.55 cents/kWhr, remainder @ 3.221 cents/kWhr
Demand charge:	\$9.87 per kW for all demand above 50 kW, based on maximum 30-minute average during each month
Fixed service fee:	\$9/month
Sales tax:	6% adder to sum of above charges

HVAC



HEATING & COOLING EFFICIENCIES

- **Energy Efficiency Ratio (EER)**: Normally used in systems greater than five (5) tons capacity.

$$\text{EER} = \frac{\text{Cooling Output (Btu/hr)}}{\text{Power Input (Watts)}}$$

- **Seasonal Energy Efficiency Ratio (SEER)**:
Total Cooling Output

$$\text{SEER} = \frac{\text{Over 12 Months (Btu)}}{\text{Total Power Input (Watt-Hours)}}$$

HEATING & COOLING EFFICIENCIES

- **Integrated Energy Efficiency Rating (IEER)**: This is a calculated measure of cooling part-load efficiency in Btu/W-h.

In Jan. 2011 DOE, along with industry partners, developed voluntary specs for 10 to 20 ton rooftop units. The specs called for a minimum 18.0 IEER.



HEATING & COOLING EFFICIENCIES

- **Coefficient of Performance (COP):** Heat Pump

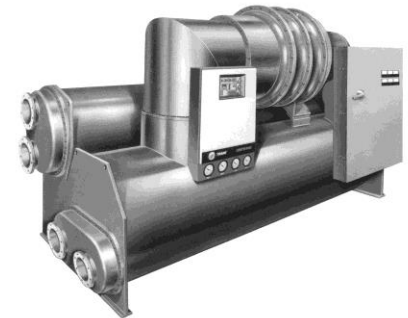
$$\text{COP} = \frac{\text{Total Heating Capacity (Btu/hr)}}{\text{Power Input (Watts)} \times 3.413}$$

- **Heating Seasonal Performance Factor (HSPF):**

$$\text{HSPF} = \frac{\begin{array}{c} \text{Total Heating Output (Heat Pump)} \\ \text{Over 12 Months (Btu)} \end{array}}{\text{Total Power Input (Watt-Hours)}}$$

HEATING & COOLING EFFICIENCIES

- ***kW/Ton:*** *This is a term normally applied to larger HVAC equipment to describe efficiency based on kW of electrical input per ton of cooling output. For example:*
 - *Package DX Equipment 1.20 kW/ton*
 - *Reciprocating Chillers 0.90 kW/ton*
 - *Screw Chillers 0.65 kW/ton*
 - *Centrifugal Chillers 0.50 kW/ton*



HVAC SYSTEMS

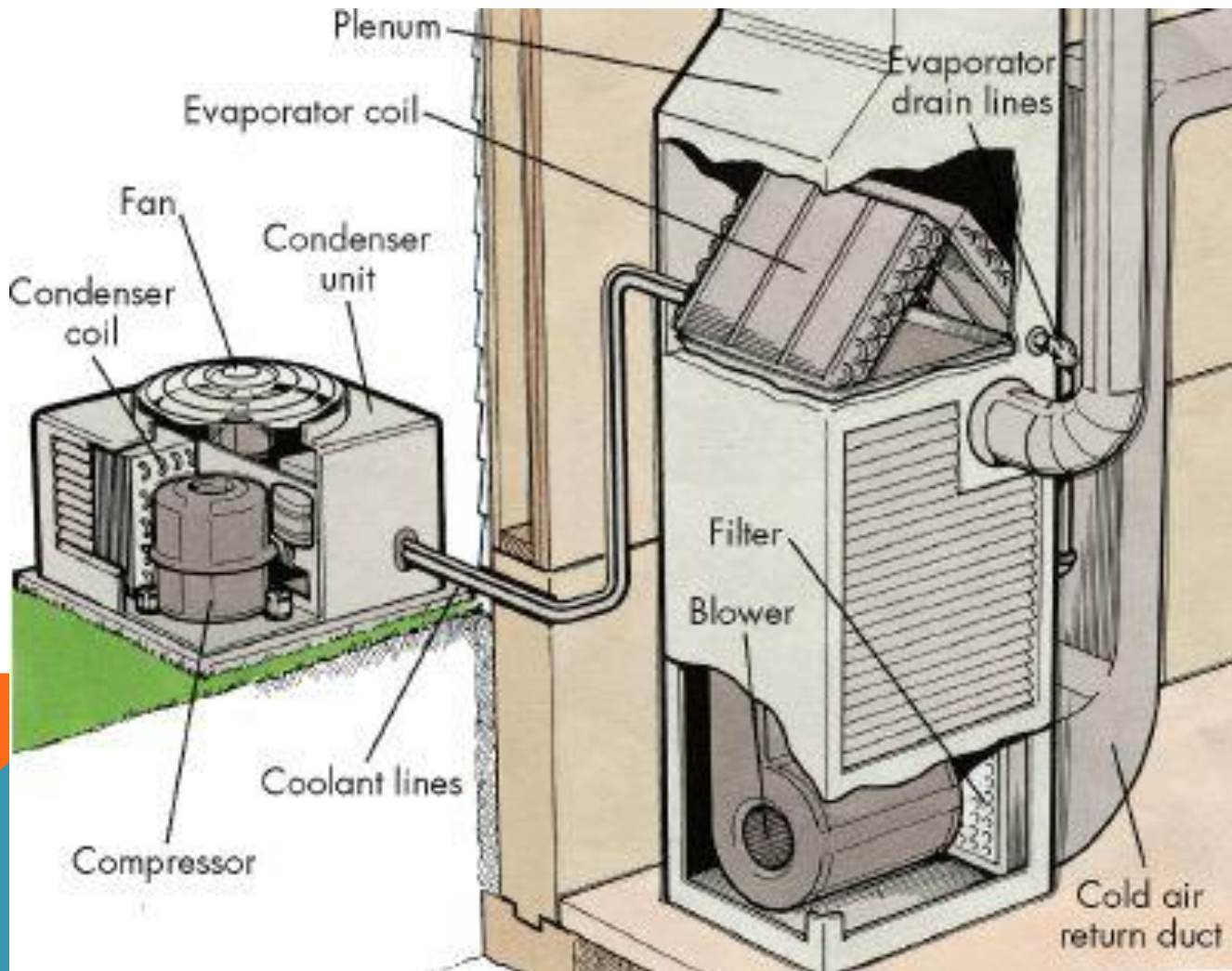
- **Typical Smaller Package DX System:**

All major components (fans/coil) are located in a single outdoor unit.



HVAC SYSTEMS

■ Typical Split DX System:

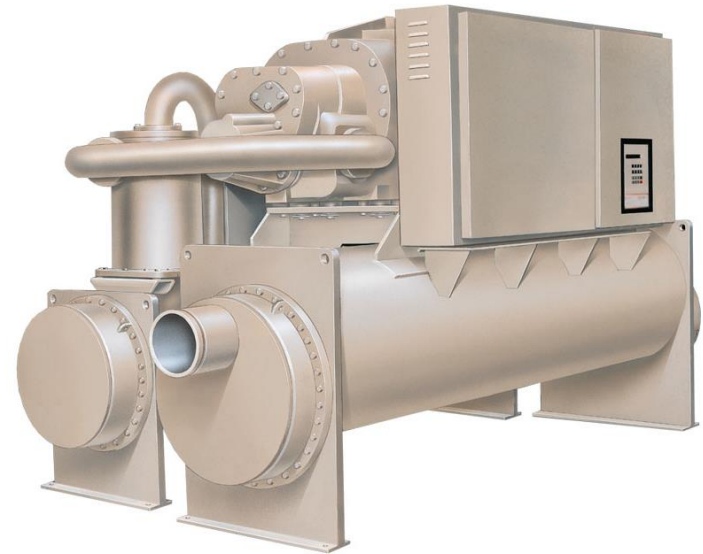


AIR-COOLED OR WATER-COOLED COMPARISON



Air-Cooled

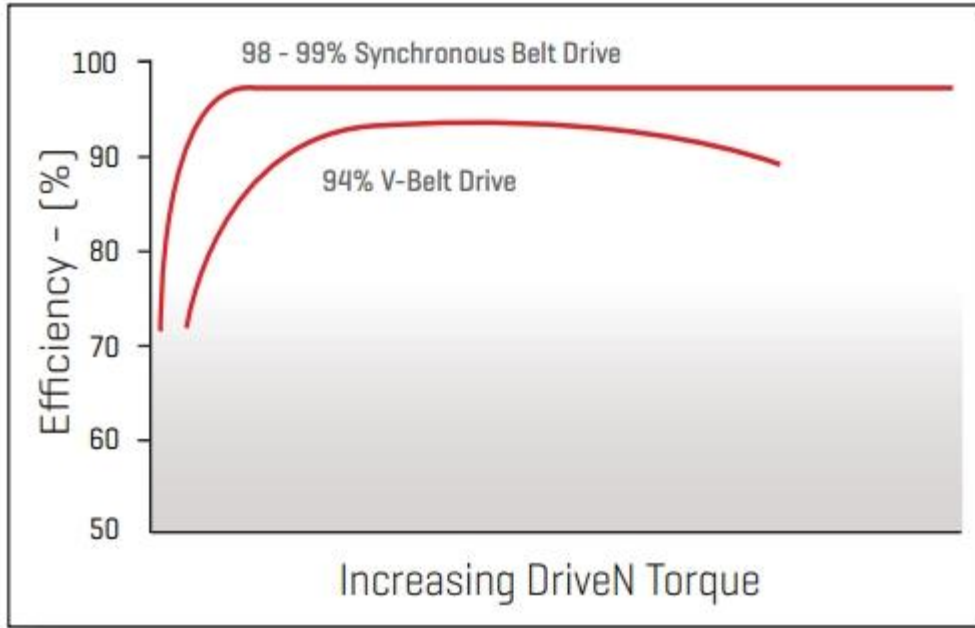
- ***Lower maintenance***
- ***Packaged system***
- ***Better low ambient operation***



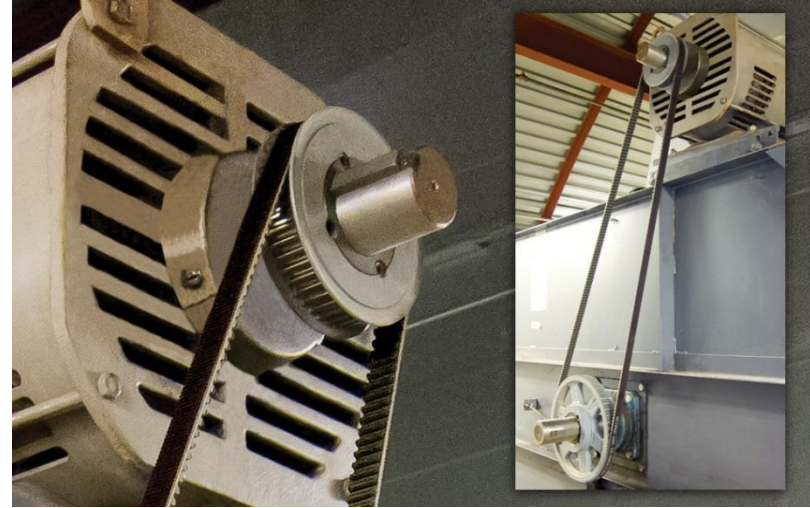
Water-Cooled

- ***Greater energy efficiency***
- ***Longer equipment life***
- ***Cooling tower to maintain***
- ***Water treatment issues***

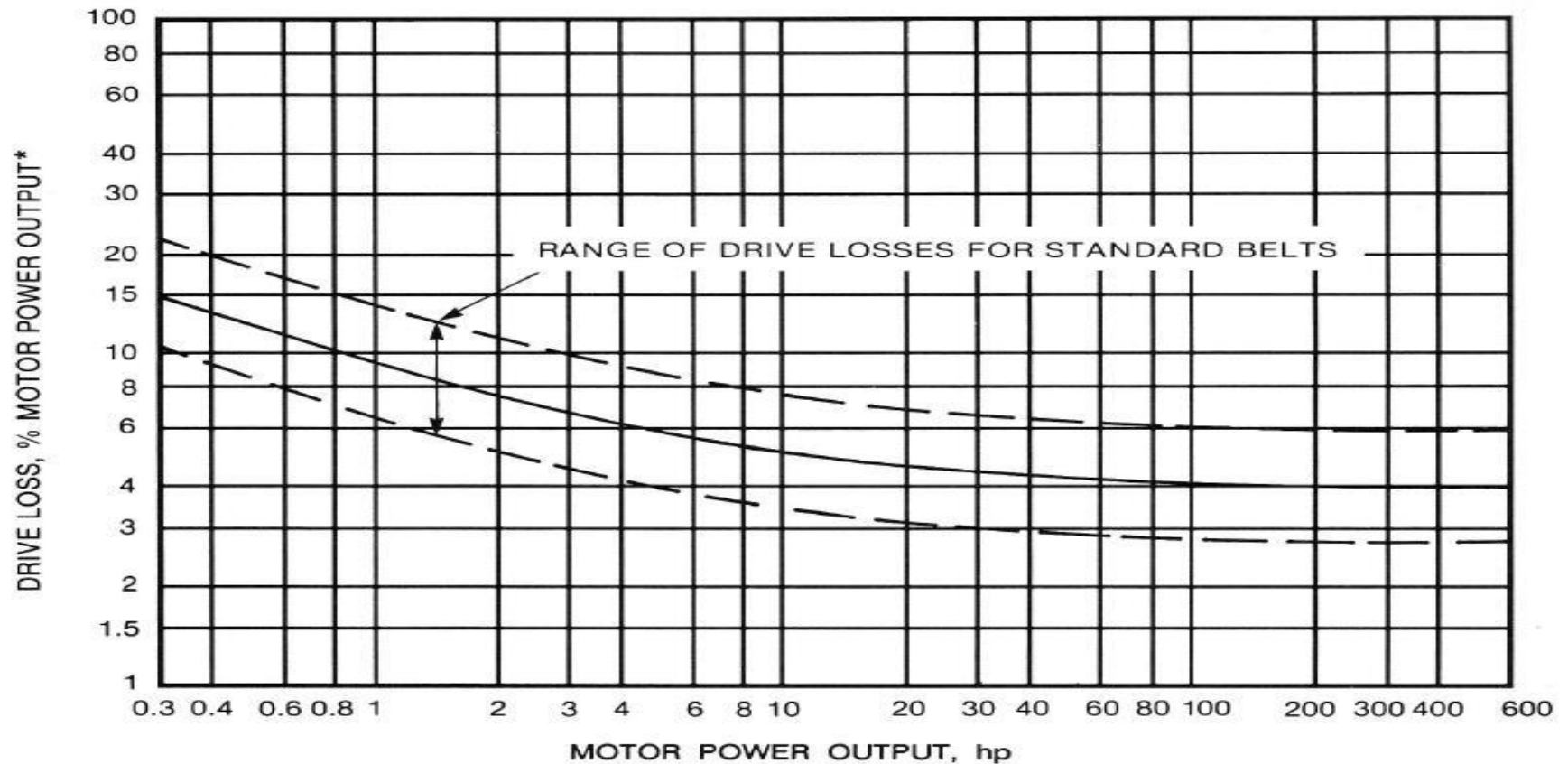
BELT DRIVE LOSSES



On average, a synchronous belt drive is 5% more efficient than a standard V-belt drive, eliminating excess energy consumption.



BELT DRIVE LOSSES



NOTE: Drive losses are based on a conventional V-belt.

The efficiency of the drive, η_d , is:

$$\eta_d = 1.0 - \text{DriveLoss}$$

Where:

η_d = Drive efficiency in decimal format
 Drive Loss = Loss calculated from AMCA 203

COMPARISON OF BELT DRIVE COSTS

Assume a 75 HP fan drive is converted to Synchronous Belts from conventional V-Belts

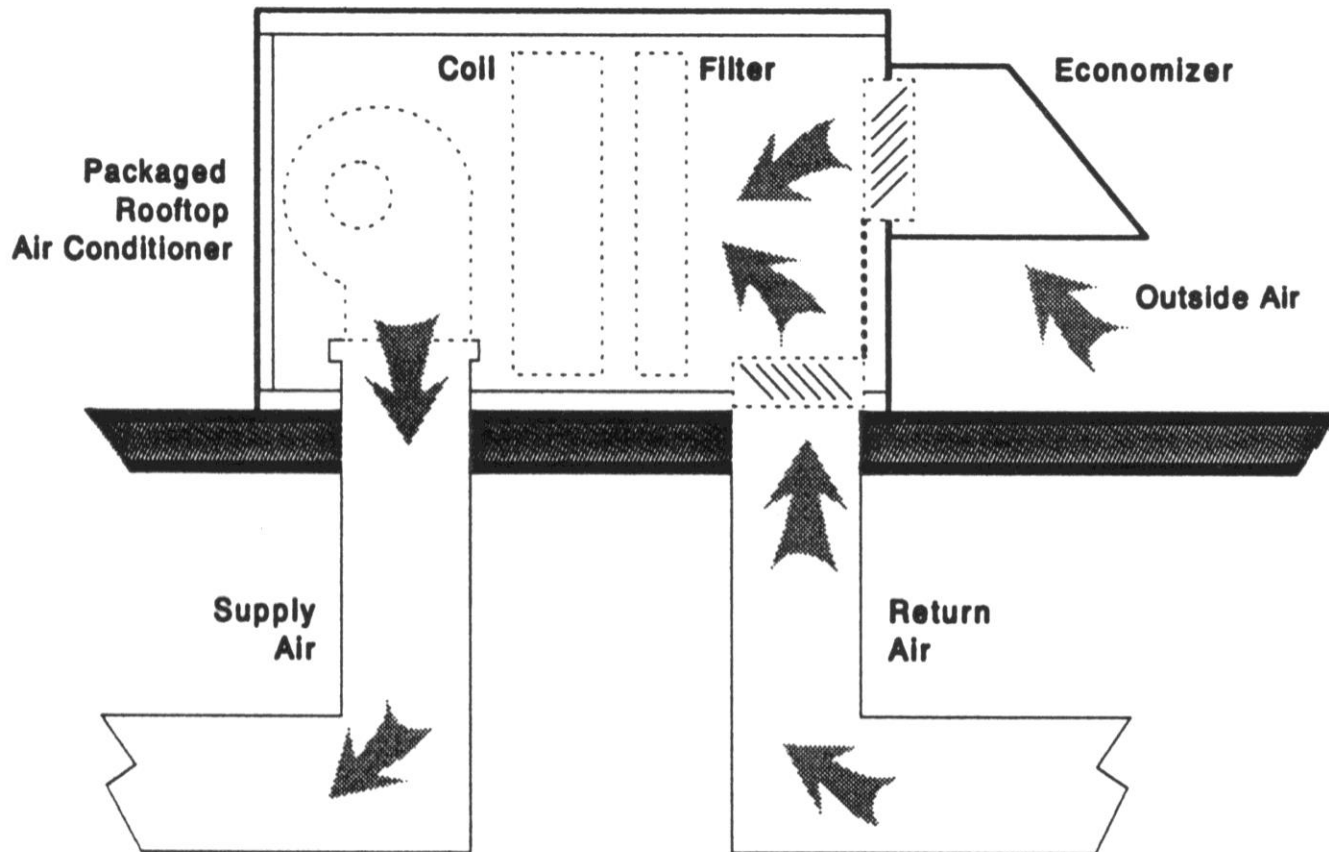
- Approximate cost of a system with V-Belts
 - One four-groove B13.6 inch sheave \$ 102
 - One four-groove B18.1 inch sheave \$ 130
 - Four B 136 V-Belts \$ 108
 - Total Cost \$ 340
- Approximate cost of a system with Synchronous Belts
 - One P52-14M-85 sprocket \$ 220
 - One P72-14M-85 sprocket \$ 320
 - One 3150-14M-14M-85 belt \$ 478
 - Total Cost \$1,018
- Assuming 5% belt slip for V-Belts and an energy cost of \$0.08/kWh and the fan operates continuously, predicted savings for the Synchronous Belt over the V-Belts is \$2,152/year
- Estimated total conversion cost is \$1,500 and the simple payback is 8.4 months

FREE COOLING


- *Airside Economizers*
- *Free Cooling with Plate and Frame Heat Exchanger*



AIRSIDE ECONOMIZERS



ENERGY MANAGEMENT TECHNIQUES

- 1. Preventive Maintenance***
 - 2. Building Management Systems***
 - 3. Commissioning/Retrocommissioning***
 - 4. Minimizing ventilation air***
 - 5. Free Cooling***
 - 6. Premium efficiency motors***
 - 7. Use of VFDs for capacity of pumps & fans***
 - 8. Other Opportunities for Saving***
- 

LIGHTING



LIGHTING

- Most lighting changes today are centered around replacing old fixtures with LED lamps
- In the last couple of years the cost of LED fixtures has decreased dramatically
- The long lamp life reduces maintenance costs significantly



LIGHTING – RETROFIT PROJECT

PROJECT:	SOUTHERN	SOUTHERN	SOUTHERN	SOUTHERN
FIXTURES BEFORE:	FIX #:1	FIX #:2	FIX #:3	FIX #:4
Fixture Type	2x4T8 High B	2x4T5 High B	400WHigh Bay	250 HID
Fixture Count	17	69	74	1
Weekly Burn Time Hours	168	168	168	168
Lamp Type	F32T8	54T5	400W MH	250 MH
Lamps per Fixture	6	6	1	1
Lamp Watts	32	54	400	250
Ballast Type	2F32elec	T5/4LMP/	400W MH	250W MH
Ballast per Fixture	3.0	1.0	1.0	1.0
Ballast Waste Watts	-6	22	60	45
Watts per Fixture	174	346	460	295
KWh per Week	496	4,010	5,718	49
KWd	2.9	23.8	34.0	0.3

FIXTURES AFTER:				
Fixture Type	LEDTubeRetro	2x4T5 High B	LED High Bay	LED2x4or1x4
Fixture Count	17	69	71	1
Weekly Burn Times Hours	68	68	68	68
Lamp Type	LED15WTUBE	LED 24W T5 T	LED240whighb	LED156W
Lamps per Fixture	6	6	1	1
Lamp Watts	15	24	240	158
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture				
Ballast Waste Watts	0			
Watts per Fixture	90	144	240	158
KWh per Week	104	675	1,158	10
KWd	1.53	9.94	17.04	0.16

MAINTENANCE BEFORE:				
Total Lamps	102	414	74	1
Replacement Lamp Price	\$3.00	\$6.50	\$55.00	\$25.00
Lamp Useful Hours	28,000	24,000	20,000	20,000
Annualized Lamp Changes	32	150	32	0
Total Lamp Change Cost	\$180	\$1,382	\$1,864	\$12
Total Ballasts	51	69	74	1
Replacement Ballast Price	\$20.00	\$120.00	\$55.00	\$55.00
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$10.61	\$20.03	\$25.19	\$12.17

MAINTENANCE AFTER:				
Total Lamps	102	414	71	1
Replacement Lamp Price				\$1.00
Lamp Useful Hours	50,000	50,000	87,360	50,000
Annualized Lamp Changes	7	29	3	
Total Lamp Change Cost	\$19	\$78	\$8	
Total Ballasts				
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$1.13	\$1.13	\$0.11	\$0.26

LIGHTING – RETROFIT PROJECT

PROJECT:	SOUTHERN	SOUTHERN	SOUTHERN	SOUTHERN
FIXTURES BEFORE:	FIX #:5	FIX #:6	FIX #:7	FIX #:8
Fixture Type	175W HID	2x4T5 High B	400WHigh Bay	175W HID
Fixture Count	10	25	3	5
Weekly Burn Time Hours	168	168	168	168
Lamp Type	175W MH	54T5	400W MH	175W MH
Lamps per Fixture	1	6	1	1
Lamp Watts	175	54	400	175
Ballast Type	175W MH	T5/4LMP/	400W MH	NONE
Ballast per Fixture	1.0	1.0	1.0	
Ballast Waste Watts	35	22	60	
Watts per Fixture	210	346	460	175
KWh per Week	352	1,453	231	147
KWd	2.1	8.6	1.3	0.8

FIXTURES AFTER:				
Fixture Type	LED2x4or1x4	LEDTubeRetro	LED HIFHBAY	LED2x4or1x4
Fixture Count	10	25	3	5
Weekly Burn Times Hours	68	42	42	168
Lamp Type	LED100WHIGHB	LED 24W T5 T	LED 24W T5 T	LED120WFLOOD
Lamps per Fixture	1	6	1	1
Lamp Watts	100	24	24	120
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture				
Ballast Waste Watts	0			
Watts per Fixture	100	144	24	120
KWh per Week	68	151	3	100
KWd	1.00	3.60	0.07	0.60

MAINTENANCE BEFORE:				
Total Lamps	10	150	3	5
Replacement Lamp Price	\$26.00	\$6.50	\$55.00	\$26.00
Lamp Useful Hours	15,000	24,000	20,000	15,000
Annualized Lamp Changes	6	54	1	2
Total Lamp Change Cost	\$167	\$501	\$76	\$83
Total Ballasts	10	25	3	
Replacement Ballast Price	\$45.00	\$120.00	\$55.00	
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$16.69	\$20.03	\$25.18	\$16.69

MAINTENANCE AFTER:				
Total Lamps	10	150	3	5
Replacement Lamp Price				
Lamp Useful Hours	90,000	50,000	50,000	90,000
Annualized Lamp Changes		7		
Total Lamp Change Cost	\$1	\$17		\$1
Total Ballasts				
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$0.10	\$0.70	\$0.12	\$0.26

LIGHTING – RETROFIT PROJECT

PROJECT:	SOUTHERN	SOUTHERN	SOUTHERN	SOUTHERN
FIXTURES BEFORE:	FIX #:9	FIX #:10	FIX #:11	FIX #:12
Fixture Type	2x4T8 High B	2x4T5 High B	400WHigh Bay	250 HID
Fixture Count	4	65	76	12
Weekly Burn Time Hours	168	168	168	168
Lamp Type	F32T8	54T5	400W MH	250 MH
Lamps per Fixture	6	6	1	1
Lamp Watts	32	54	400	250
Ballast Type	2F32elec	T5/4LMP/	400W MH	250W MH
Ballast per Fixture	3.0	1.0	1.0	1.0
Ballast Waste Watts	-6	22	60	45
Watts per Fixture	174	346	460	295
KWh per Week	116	3,778	5,873	594
KWd	0.7	22.4	34.9	3.5

FIXTURES AFTER:				
Fixture Type	LEDTubeRetro	LEDTubeRetro	LED High Bay	LED2x4or1x4
Fixture Count	4	65	76	12
Weekly Burn Times Hours	168	168	168	168
Lamp Type	LED15WTUBE	LED 12WTUBE	LED240whighb	LED100WHIGHB
Lamps per Fixture	6	6	1	1
Lamp Watts	15	12	240	100
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture				
Ballast Waste Watts	0			
Watts per Fixture	90	72	240	100
KWh per Week	60	786	3,064	201
KWd	0.36	4.68	18.24	1.20

MAINTENANCE BEFORE:

Total Lamps	24	390	76	12
Replacement Lamp Price	\$3.00	\$6.50	\$55.00	\$25.00
Lamp Useful Hours	28,000	24,000	20,000	20,000
Annualized Lamp Changes	7	141	33	5
Total Lamp Change Cost	\$42	\$1,302	\$1,915	\$145
Total Ballasts	12	65	76	12
Replacement Ballast Price	\$20.00	\$120.00	\$55.00	\$55.00
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$10.62	\$20.03	\$25.19	\$12.08

MAINTENANCE AFTER:

Total Lamps	24	390	76	12
Replacement Lamp Price				
Lamp Useful Hours	50,000	50,000	87,360	90,000
Annualized Lamp Changes	4	68	8	1
Total Lamp Change Cost	\$11	\$182	\$20	\$3
Total Ballasts				
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$2.80	\$2.80	\$0.27	\$0.26

LIGHTING – RETROFIT PROJECT

PROJECT:	SOUTHERN	SOUTHERN	SOUTHERN	SOUTHERN
FIXTURES BEFORE:	FIX #:13	FIX #:14	FIX #:15	FIX #:16
Fixture Type	175W HID	1x4	2x4	8' STRIP
Fixture Count	26	20	6	33
Weekly Burn Time Hours	168	168	168	168
Lamp Type	175W MH	F32T8	F32T8	F96T12ES
Lamps per Fixture	1	2	4	2
Lamp Watts	175	32	32	60
Ballast Type	175W MH	2F32elec	2F32elec	2F96std
Ballast per Fixture	1.0	1.0	1.0	1.0
Ballast Waste Watts	35	-6	-6	24
Watts per Fixture	210	58	122	144
KWh per Week	917	194	122	798
KWd	5.4	1.1	0.7	4.7

FIXTURES AFTER:				
Fixture Type	LED Flood/Wa	LEDTubeRetro	LEDTubeRetro	LEDTubeRetro
Fixture Count	26	20	6	33
Weekly Burn Times Hours	168	168	168	168
Lamp Type	LED120WFLOOD	LED15WTUBE	LED15WTUBE	LED15WTUBE
Lamps per Fixture	1	2	4	4
Lamp Watts	120	15	15	15
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture	1.0			
Ballast Waste Watts	0			
Watts per Fixture	120	30	60	60
KWh per Week	524	100	60	332
KWd	3.12	0.60	0.36	1.98

MAINTENANCE BEFORE:

Total Lamps	26	40	24	66
Replacement Lamp Price	\$26.00	\$3.00	\$3.00	\$5.50
Lamp Useful Hours	15,000	28,000	28,000	10,000
Annualized Lamp Changes	15	12	7	57
Total Lamp Change Cost	\$434	\$71	\$42	\$471
Total Ballasts	26	20	6	33
Replacement Ballast Price	\$45.00	\$20.00	\$20.00	\$23.00
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$16.69	\$3.54	\$7.08	\$14.28

MAINTENANCE AFTER:

Total Lamps	26	40	24	132
Replacement Lamp Price				
Lamp Useful Hours	90,000	50,000	50,000	50,000
Annualized Lamp Changes	3	7	4	23
Total Lamp Change Cost	\$7	\$19	\$11	\$62
Total Ballasts	26			
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$0.26	\$0.93	\$1.87	\$1.87

LIGHTING – RETROFIT PROJECT

PROJECT:	SOUTHERN	SOUTHERN	SOUTHERN	SOUTHERN
FIXTURES BEFORE:	FIX #:17	FIX #:18	FIX #:19	FIX #:20
Fixture Type	1x4	2x4	2x4	2x2
Fixture Count	30	22	64	3
Weekly Burn Time Hours	168	168	168	168
Lamp Type	F40T12ES	F40T12ES	F40T12ES	F40T12U
Lamps per Fixture	2	4	3	2
Lamp Watts	34	34	34	40
Ballast Type	2F40es	2F40es	3F40elec	2F40es
Ballast per Fixture	1.0	2.0	1.0	1.0
Ballast Waste Watts	4	4	-15	4
Watts per Fixture	72	144	87	84
KWh per Week	362	532	935	42
KWd	2.1	3.1	5.5	0.2

FIXTURES AFTER:				
Fixture Type	LEDTubeRetro	LEDTubeRetro	LEDTubeRetro	LEDTubeRetro
Fixture Count	30	22	64	3
Weekly Burn Times Hours	168	168	168	168
Lamp Type	LED15WTUBE	LED15WTUBE	LED15WTUBE	LED2'9WTUBE
Lamps per Fixture	2	4	3	2
Lamp Watts	15	15	15	9
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture				
Ballast Waste Watts	0			
Watts per Fixture	30	60	45	18
KWh per Week	151	221	483	9
KWd	0.90	1.32	2.88	0.05

MAINTENANCE BEFORE:				
Total Lamps	60	88	192	6
Replacement Lamp Price	\$1.75	\$1.75	\$1.75	\$8.00
Lamp Useful Hours	15,000	15,000	15,000	8,300
Annualized Lamp Changes	35	51	111	6
Total Lamp Change Cost	\$154	\$227	\$494	\$67
Total Ballasts	30	44	64	3
Replacement Ballast Price	\$17.00	\$17.00	\$37.00	\$17.00
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$5.15	\$10.30	\$7.72	\$22.48

MAINTENANCE AFTER:				
Total Lamps	60	88	192	6
Replacement Lamp Price				
Lamp Useful Hours	50,000	50,000	50,000	50,000
Annualized Lamp Changes	10	15	34	1
Total Lamp Change Cost	\$28	\$41	\$90	\$3
Total Ballasts				
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$0.93	\$1.87	\$1.40	\$0.93

LIGHTING – RETROFIT PROJECT

PROJECT:	OUTSIDE	OUTSIDE	OUTSIDE	OUTSIDE
FIXTURES BEFORE:	FIX #:1	FIX #:2	FIX #:3	FIX #:4
Fixture Type	EXIT	Flood/Pole	Flood/Pole	Flood/Pole
Fixture Count	22	89	11	8
Weekly Burn Time Hours	168	84	84	84
Lamp Type	EXIT-20	175W MH	400W MH	250 MH
Lamps per Fixture	2	1	1	1
Lamp Watts	20	175	400	250
Ballast Type	NONE	175W MH	400W MH	250W MH
Ballast per Fixture		1.0	1.0	1.0
Ballast Waste Watts		35	60	45
Watts per Fixture	40	210	460	295
KWh per Week	147	1,569	425	198
KWd	0.8	18.6	5.0	2.3

FIXTURES AFTER:				
Fixture Type	New LED Exit	LED Flood/Wa	LED Flood/Wa	LED Flood/Wa
Fixture Count	22	89	11	8
Weekly Burn Times Hours	168	84	84	84
Lamp Type	LED EXIT	LED120WFLOOD	LED187W	LED120WFLOOD
Lamps per Fixture	2	1	1	1
Lamp Watts	2	120	187	120
Ballast Type	NONE	NONE	NONE	NONE
Ballast per Fixture				
Ballast Waste Watts	0			
Watts per Fixture	4	120	187	120
KWh per Week	14	897	172	80
KWd	0.09	10.68	2.06	0.96

MAINTENANCE BEFORE:				
Total Lamps	44	89	11	8
Replacement Lamp Price	\$2.50	\$26.00	\$55.00	\$25.00
Lamp Useful Hours	3,500	15,000	20,000	20,000
Annualized Lamp Changes	110	25	2	1
Total Lamp Change Cost	\$568	\$743	\$138	\$48
Total Ballasts		89	11	8
Replacement Ballast Price		\$45.00	\$55.00	\$55.00
Ballast Replacement Factor				
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$25.81	\$8.35	\$12.58	\$6.05

MAINTENANCE AFTER:				
Total Lamps	44	89	11	8
Replacement Lamp Price	\$24.00			
Lamp Useful Hours	50,000	90,000	50,000	90,000
Annualized Lamp Changes	8	4	1	
Total Lamp Change Cost	\$205	\$12	\$3	\$1
Total Ballasts				
Replacement Ballast Price				
Ballast Replacement Factor				
New Ballast (Y/N)	N	N	N	N
Annualized Ballast Changes				
Total Ballast Change Cost				
Annualized Maint. per Fixture	\$9.32	\$0.13	\$0.23	\$0.13

LIGHTING – RETROFIT PROJECT

PROJECT: OUTSIDE	
FIXTURES BEFORE:	FIX #:5
Fixture Type	Flood/Pole
Fixture Count	2
Weekly Burn Time Hours	84
Lamp Type	1000W MH
Lamps per Fixture	1
Lamp Watts	999
Ballast Type	1000W MH
Ballast per Fixture	1.0
Ballast Waste Watts	81
Watts per Fixture	1,080
KWh per Week	181
KWd	2.1

FIXTURES AFTER:	
Fixture Type	LED Flood/Wa
Fixture Count	2
Weekly Burn Times Hours	84
Lamp Type	LED427w
Lamps per Fixture	1
Lamp Watts	427
Ballast Type	NONE
Ballast per Fixture	
Ballast Waste Watts	0
Watts per Fixture	427
KWh per Week	71
KWd	0.85

MAINTENANCE BEFORE:	
Total Lamps	2
Replacement Lamp Price	\$55.00
Lamp Useful Hours	12,000
Annualized Lamp Changes	1
Total Lamp Change Cost	\$42
Total Ballasts	2
Replacement Ballast Price	\$90.00
Ballast Replacement Factor	
Annualized Ballast Changes	
Total Ballast Change Cost	
Annualized Maint. per Fixture	\$21.05

MAINTENANCE AFTER:	
Total Lamps	2
Replacement Lamp Price	
Lamp Useful Hours	40,000
Annualized Lamp Changes	
Total Lamp Change Cost	\$1
Total Ballasts	
Replacement Ballast Price	
Ballast Replacement Factor	
New Ballast (Y/N)	N
Annualized Ballast Changes	
Total Ballast Change Cost	
Annualized Maint. per Fixture	\$0.30

LIGHTING – RETROFIT PROJECT

QUANTITY	DESCRIPTION	PRICE	EXTENSION
1. 26	8' strip - 6 T8 lamp fixtures - retrofit - with 6 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps with internal driver	\$ 158.80	\$4,128.80
2. 140	2x4 - 6 T5 lamp fixtures highbay and lowboy - retrofit - with 6 new 4' LED T5 frosted Tube (5000 K) 24 Watt Lamps	\$ 188.80	\$26,432.00
3. 138	400W HID fixtures change to 175 new 2x4 - 240 Watt (5000 K) LED fixtures	\$ 530.80	\$73,250.40
4. 13	250W HID fixtures change to 13 new 2x4 - 156 Watt (5000 K) LED fixtures	\$ 299.80	\$3,897.40
5. 38	175W HID fixtures change to 38 new flood - 120 Watt (5000 K) LED fixtures	\$ 604.80	\$22,982.40
6. 32	1x4 - 2 T8 lamp fixtures office and plant floor areas - retrofit - with 2 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 58.80	\$1,881.60
7. 14	2x4 - 4 T8 lamp fixtures office and plant floor areas - retrofit - with 4 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 78.80	\$1,103.20
8. 33	8' strip - 4 T8 lamp fixtures office and plant floor areas - retrofit - with 4 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 80.80	\$2,666.40
9. 30	1x4 - 2 T8 lamp fixtures office and plant floor areas - retrofit - with 2 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 78.80	\$2,364.00
10. 22	2x4 - 4 T8 lamp fixtures office and plant floor areas - retrofit - with 4 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 88.80	\$1,953.60
11. 64	2x4 - 3 T8 lamp fixtures office and plant floor areas - retrofit - with 4 new 4' LED T8 frosted Tube (5000 K) 15 Watt Lamps	\$ 67.80	\$4,339.20
12. 3	2x2 - 2 T12 lamp fixtures office areas - retrofit - with 2 new 2' LED T8 frosted Tube (5000 K) 9 Watt Lamps	\$ 65.80	\$197.40
13. 201	UEA fixture occupancy sensors	\$ 44.80	\$9,004.80
14. 10	UEA wall occupancy sensors	\$ 128.00	\$1,288.00
15. 22	UEA LED EXIT SIGN CONVERSION, LESS THAN 4 WATTS outside fixtures	\$ 58.80	\$1,293.60
16. 11	400W HID flood fixtures change to 11 new 187 Watt flood (5000 K) LED fixtures	\$ 880.80	\$9,688.80
17. 89	175W HID flood fixtures change to 89 new 120 Watt flood (5000 K) LED fixtures	\$ 604.80	\$53,827.20
18. 8	250W HID flood fixtures change to 8 new 187 Watt flood (5000 K) LED fixtures	\$ 604.80	\$4,838.40
19. 2	1000W HID flood fixtures change to 2 new 427 Watt flood (5000 K) LED fixtures	\$ 1,238.80	\$2,477.60
REPORT TO INCLUDE :			
ECONOMIC LIGHTING SURVEY, AND TURN-KEY PROPOSAL			
SUBTOTAL			\$227,614.80
SALES TAX			\$ NA
SHIPPING AND HANDLING			ALLOWED
TOTAL			\$227,614.80

LIGHTING - RETROFIT PROJECT

LIGHTING ENERGY

SAVINGS SUMMARY

SAVINGS SUMMARY

ANNUAL CASH SAVINGS

\$71,957

CAPITAL RECOVERY

37.96 Months

RETURN ON INVESTMENT

31.61 %

CONVERSION SUMMARY

EFFECTIVE COST PER KWh: 0.0600
AVERAGE WEEKLY LIGHTING HOURS: 133

KWh RATE:

BEFORE CONVERSION

AFTER CONVERSION

TOTAL FIXTURES:	697	694
TOTAL LAMPS:	1,917	1,980
TOTAL BALLASTS:	734	26
LIGHTING KWh PER MONTH:	126,763	41,192
LIGHTING KWh:	188	84
WATTAGE PER SQUARE FT:	*****	*****

ESTIMATED IMPROVEMENT COST AND SAVINGS

ESTIMATED COST:	\$227,614	ANNUAL KWh SAVINGS:	\$61,610
NET IMPROVEMENT COST:	\$227,614	ANNUAL KWh SAVINGS:	N/A, ,
SAVINGS FOR FIVE YEARS:	\$359,785	ANNUAL HVAC SAVINGS:	\$0
SAVINGS FOR TEN YEARS:	\$719,570	ANNUAL MAINTENANCE SAVINGS:	\$10,347
		TOTAL ANNUAL SAVINGS:	\$71,957

ANNUAL ENVIRONMENTAL SAVINGS

POUNDS OF CARBON DIOXIDE:	1,540,278
POUNDS OF SULFUR DIOXIDE:	10,884,631
POUNDS OF NITRUS OXIDE:	2,669,815

LIGHTING – RETROFIT PROJECT

LIGHTING CONFIGURATION:

	BEFORE	AFTER
Fixtures:	697	694
Lamps:	1,917	1,980
Ballasts:	734	26

MONTHLY POWER:

	BEFORE	AFTER
KWh:	126,763	41,244
KWd:	188.2	84.4
Av HVAC KWh:	0	0
Cost:	\$7,605	\$2,474

ANNUALIZED LIGHTING POWER USE, COST & SAVINGS:

		COST BEFORE	COST AFTER	SAVINGS
POWER	Lighting KWh:	1,521,156	494,928	1,026,228
	Lighting KWd:	188.25	84.42	103.83
	Lighting AC KWh:	0	0	0
	Heat Makeup KWh:	0	0	0
DOLLARS	Lighting KWh \$\$:	\$91,269	\$29,696	\$61,573
	Lighting KWd \$\$:	\$0	\$0	\$0
	Lighting AC Power \$\$:	\$0	\$0	\$0
	Heating Makeup \$\$:	\$0	\$0	\$0
	Lighting HVAC \$\$:	\$0	\$0	\$0
	TOTAL POWER \$\$:	\$91,269	\$29,696	\$61,573
	TOTAL MAINTENANCE \$\$:	\$11,170	\$822	\$10,348

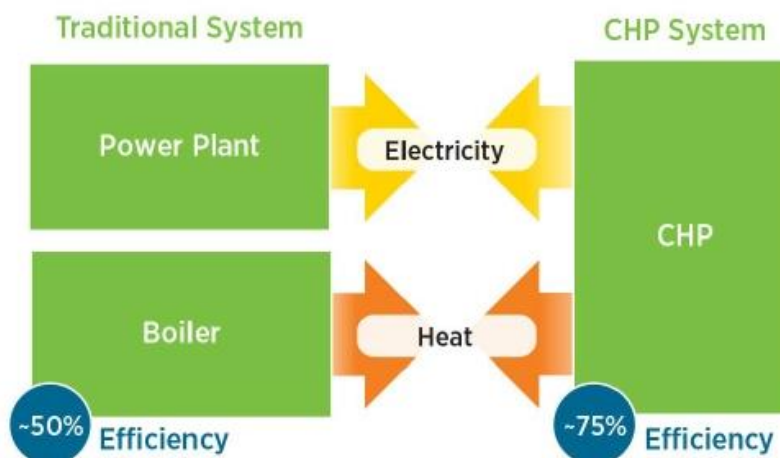
COMBINED HEAT & POWER



OPPORTUNITIES FOR COMBINED HEAT AND POWER


CHP: A Key Part of Our Energy Future

- Form of Distributed Generation (DG)
- An integrated system
- Located at or near a building / facility
- Provides at least a portion of the electrical load and
- Uses thermal energy for:
 - Space Heating / Cooling
 - Process Heating / Cooling
 - Dehumidification




CHP provides efficient, clean, reliable, affordable energy – today and for the future.

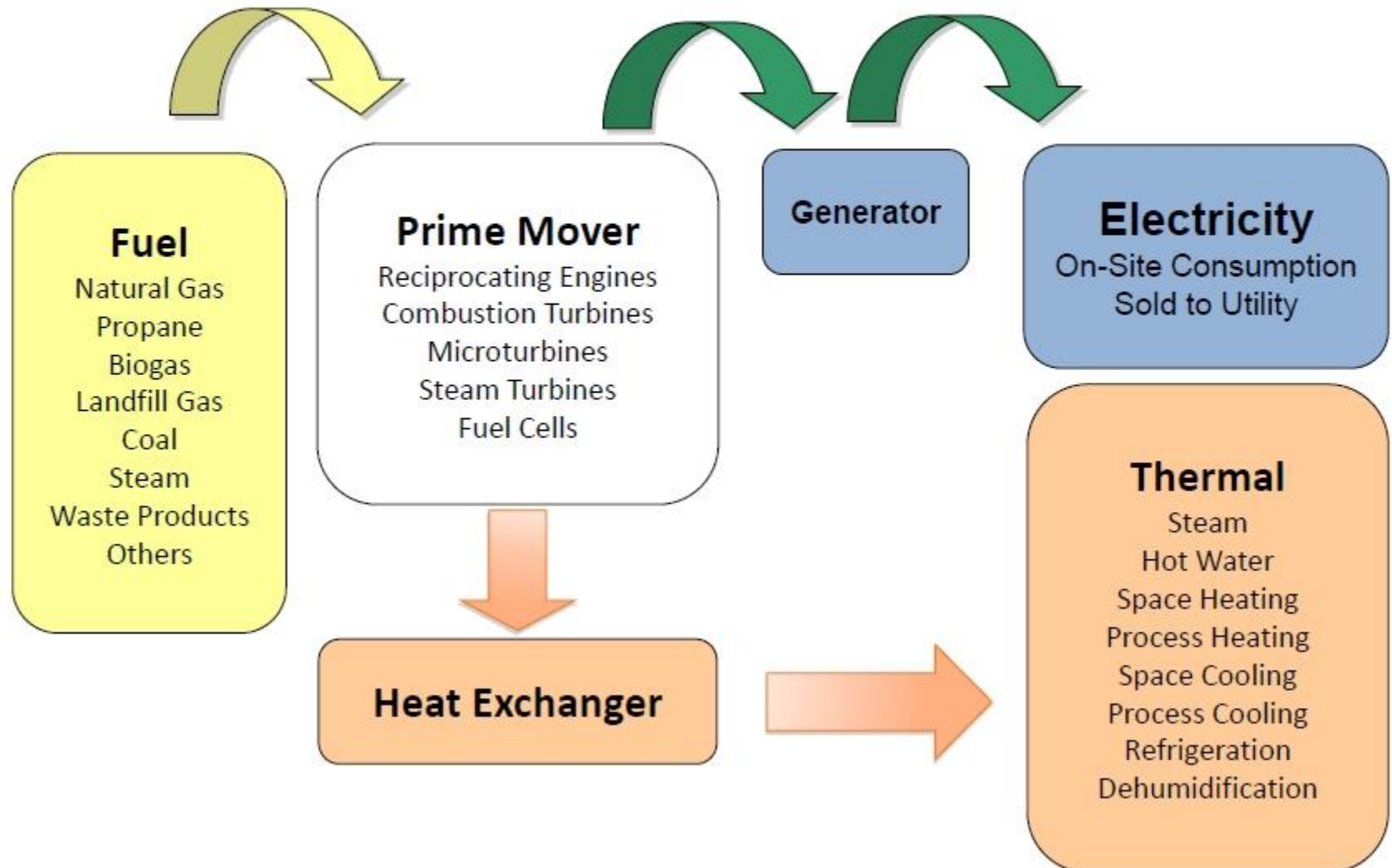
OPPORTUNITIES FOR COMBINED HEAT AND POWER

- Biogas from the digester can be used as fuel to generate electricity and produce useful heat for the digester or space heating
 - Natural gas costs about \$4.00 to \$6.00 per MMBtu, depending on where you live and how much you purchase
 - At \$0.08/kWh, electricity costs \$23.44 per MMBtu
 - By burning biogas in an engine/turbine/boiler and producing electricity first the waste heat from the power generation can be used in the digester or as space heat producing overall efficiencies in the 65% to 80% range
- 

OPPORTUNITIES FOR COMBINED HEAT AND POWER

- CHP systems can use a variety of prime movers
 - Reciprocating engines
 - Microturbines
 - Fuel cells
 - A typical WWTP processes 100 gal/day of wastewater for every person served
 - About 1 ft³ of digester gas can be produced by an anaerobic digester per person per day
 - Anaerobic digester gas from WWTP's is usually 60 to 70% methane with the rest primarily CO₂
 - HHV is 610 – 715 Btu/ft³ and LHV is 550 – 650 Btu/ft³
 - For natural gas the HHV is ~1024 Btu/ft³
- 

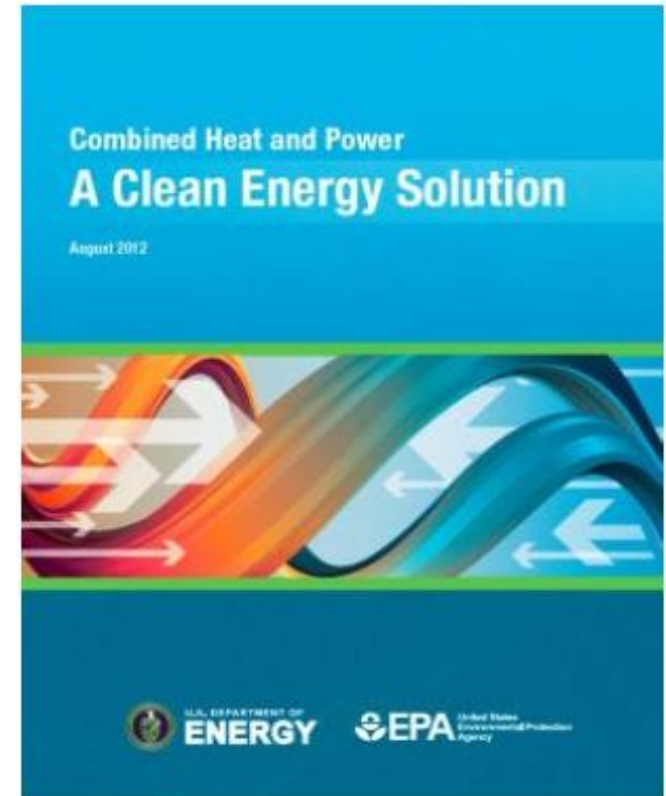
CHP System Schematic



Emerging Regulatory Drivers for CHP

- Benefits of CHP recognized by policymakers
 - President Obama signed an Executive Order to accelerate investments in industrial EE and CHP on 8/30/12 that sets national goal of 40 GW of new CHP installation over the next decade
 - State Portfolio Standards (RPS, EEPS, Tax Incentives, Grants, standby rates, etc.)
 - Water-Energy Nexus: Challenges and Opportunities – report by US DOE, 2014
- Favorable pricing for natural gas supply and price in North America
- Environmental drivers
- Utilities finding economic value
- Energy resiliency and critical infrastructure


DOE / EPA CHP Report (8/2012)



Executive Order: <http://www.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency>

Report:
http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_clean_energy_solution.pdf

Facility Drivers for CHP in WWTFs

- Desire to reduce energy costs
 - Importance of energy resiliency
 - Sustainability planning
 - Enhanced Reliability
 - emissions reduction
 - Biogas production
 - Utility load shedding
 - Availability of incentives
 - Enhanced bio-solid management
 - “Green” publicity
- 

CHP Installation Status in U.S. WWTFs

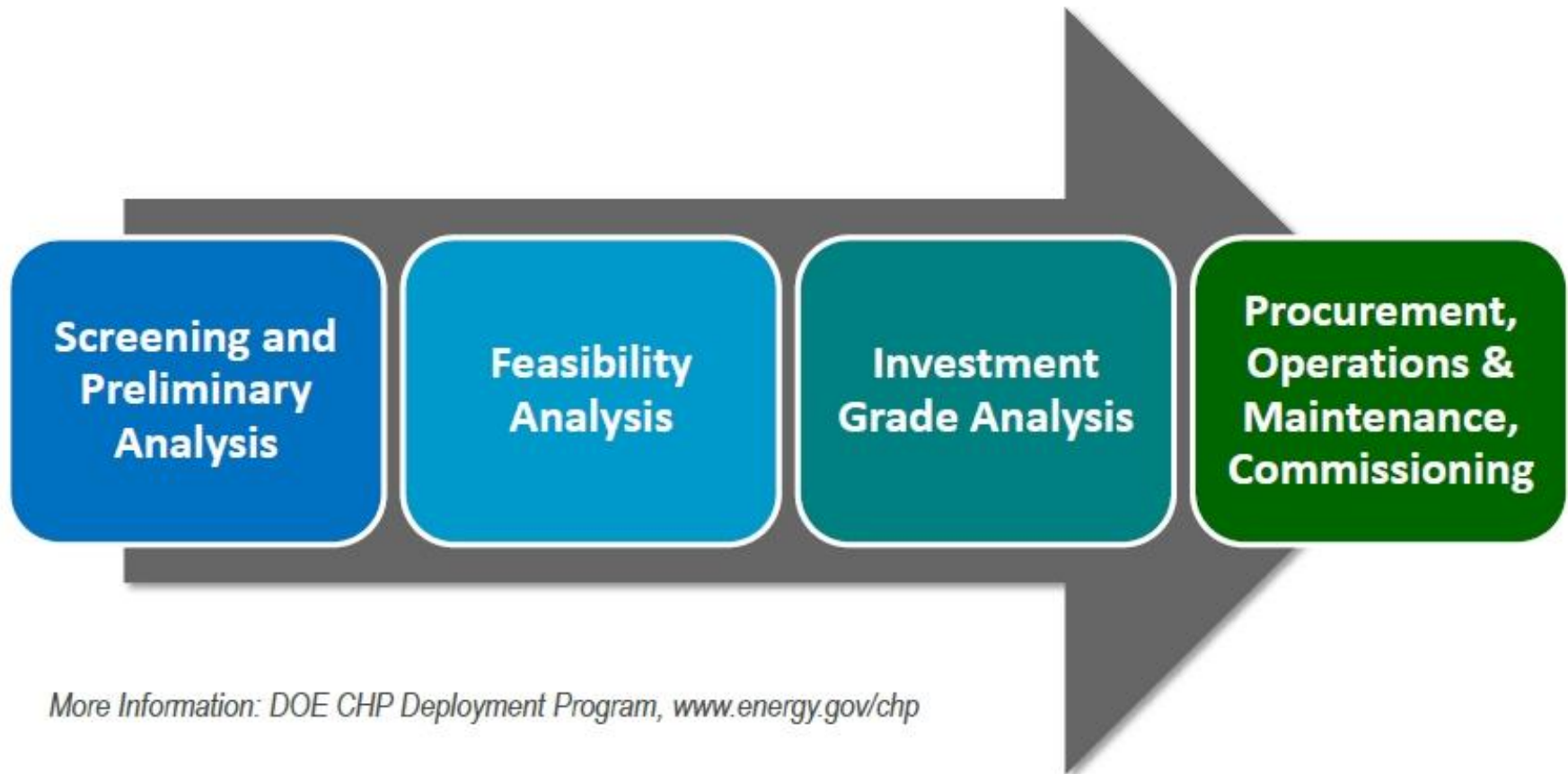
211 WWTFs are operating
CHP today

CHP capacity in WWTFs
totals ~707.4 MW

Table: Prime Mover Type in WWTFs

Prime Mover Type	# of CHP Systems	CHP Gen. Capacity (MW)
Combustion Turbine	16	349.3
Reciprocating Engine	134	266.0
Boiler/Steam Turbine	5	44.6
Microturbine	38	6.8
Fuel Cell	16	12.1
Combined Cycle	1	28.0
Organic Rankine Cycle	1	0.6
Total	211	707.377

What is the Project Development Process for a CHP Project?



Following the Project Development process can help reduce risk later down the road.

CHP in WWTFs – Early Questions

1. How reliable is the electricity coming into your facility?
2. What is the average price of electricity and natural gas you are paying?
3. What sources of heat are needed within the facility?
4. Can you provide one year's worth of electric and thermal energy bills / consumption?
5. What is the critical load in power outages?
6. What is the maximum and average flow of your facility (MGD)?
7. How do you treat your waste? Do you utilize anaerobic digesters? If so...
 - a) Are you producing biogas? How much? Does it change seasonally? How is the biogas currently being used (e.g. flaring, electric generation, thermal)?
 - b) Have you had an analysis of your biogas? What level of contaminants are in the biogas (e.g. H₂S, moisture, siloxanes)?
 - c) What additional revenue streams can result from a biogas CHP system?

What Helps Make a Biogas CHP Project Feasible in a WWTF?

- Maximizing revenue streams
- Using co-digestion
 - Some co-digestion feedstocks are amazing producers of biogas, including animal waste and food processing waste
- Having a proper design for the climate zone and technology choice matches solids content of the feedstock
- Scrubbing the biogas – biogas can contain H_2S , Siloxanes, CO_2 , and other impurities that could harm the CHP system and lower the fuel heat content
- Maximizing heat recovery
- Strong O&M support

Source: USDA, US EPA, & US DOE Biogas Opportunities Roadmap

Project Snapshot:

Flexibility Between Boilers and CHP System

Rochester Wastewater Reclamation Plant

Rochester, MN

Application/Industry: Wastewater Treatment

Capacity (MW): 2-1 MW engines

Prime Mover: Reciprocating Engine

Fuel Type: Biogas

Thermal Use: Heat for the Digestion Process, Feed Gas Preheat, Building Heat

Testimonial: The facility produces upwards of 338,000 cu. ft. of biogas daily. By burning these in lean-burn engines, the facility has been able to achieve annual energy savings of \$650,000.



Aerial View of Rochester Wastewater Reclamation Plant



One of the two 1 MW engines

Project Snapshot:

Partnering with local utility

Albert Lea Wastewater Treatment Facility

Albert Lea, MN

Application/Industry: Wastewater Treatment

Capacity (MW): 4-30kW Engines

Prime Mover: Microturbines

Fuel Type: Biogas

Thermal Use: Heat for the Digestion Process, Building Heat

Installation Year: 2004

Testimonial: "It gives us the ability to use the methane gas already generated at the plant. We are able to take a waste product and use it for something beneficial." – Steve Jahnke, City Engineer

"We are impressed with the effectiveness of the technology, and hope to encourage other Minnesota cities to consider capturing methane biogas to not only protect Minnesota's environment, but to save energy. The possibilities of the turbines don't end with energy production; they could also bring new businesses, and businesses are looking for cities that have vision." - Lois Mack, Minnesota Department of Commerce



30 kW Capstone Microturbines

Project Snapshot:

Hauled Waste Yields Significant Savings

Des Moines Wastewater Reclamation Authority

Des Moines, IA

Application/Industry: Wastewater Treatment

Capacity (MW): 4.6 MW

Prime Mover: 5 Reciprocating Engines

Fuel Type: Biogas

Thermal Use: Heat for the Digestion Process,
Building Heat

Testimonial: DMWRA hauls in high strength waste, enough to account for 40% of their organic loading. This gas helps the facility produce around 1.6 million cu. ft. of biogas daily which is enough to power 5 reciprocating engines with still having some supply leftover to sell to a neighboring manufacturing facility.



600 kW Engine. Source: Iowa Environmental Council



1.4 MW Engine. Source: Iowa Environmental Council

Project Snapshot:

Moving towards net-zero

Danville Sanitary District

Danville, IL

Application/Industry: Wastewater Treatment

Capacity (MW): 150 kW

Prime Mover: Reciprocating Engine

Fuel Type: Biogas

Thermal Use: Heat for the Digestion Process, Building Heat

Installation Year: 2013

Testimonial: *"What's not to like about using sewage to generate heat and electricity while also reducing gas emissions into the atmosphere?"*

- Danville is currently looking at increasing gas production for a second engine



150kW Reciprocating Engine



Gas Conditioning Equipment

QUESTIONS ?????

